Production of Commodities and Iron Economy in Early China: A Case Study of a Western Han Iron Foundry at Taicheng

Production of Commodities and Iron Economy in Early China: A Case Study of a Western Han Iron Foundry at Taicheng

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Abstract

How the exchange of commodities and control over resources shaped the social world is a major concern in anthropology. In the domain of history, the form and structure of market economy during the Han period is also a long debated issue. Consequently, the study of imperial control over commodities within an anthropological framework is a promising avenue that sheds new light on debates about the Han commodity economy. This dissertation addresses the production and distribution system of the Han iron industry in order to investigate the nature of commodities and resource control. This project integrates metallurgical and zooarchaeological approaches to analyzing manufacturing remains at an iron foundry site named Taicheng, as well as iron objects from various cemeteries in the Guanzhong basin, Shaanxi, the capital area of the Western Han Empire (202 BCE-9 CE). The results provide new evidence demonstrating the "commodity economy" of iron in the capital area, in fact, functioned as a multi-level network system. Even within the same category of iron products, the degree of commodification and the scope of market networks widely varied in the Western Han period, a fact that has been overlooked in previous literature. In addition, the transportation of iron goods to the capital created a massive market network connecting different parts of the Empire and generated the momentum for the capital to dominate over its eastern territory.

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CHAPTER 1

INTRODUCTION

1.1 Craft Production and Recent Development in Chinese Archaeology

Craft production has recently become an essential issue in the study of Early China. Under the influence of anthropological models, Chinese archaeology has recently witnessed an emerging effort to articulate the issue of social complexity through the lens of craft specialization (Bennett 2007; Cunnar 2007; Dai 2006; Flad 2011; Hung 2011; Underhill 1991, 2002; Yi, et al. 2013). These craft specialization models (e.g. Campbell, et al. 2011; Franck 2010; Li, et al. 2011; Li 2007; Liu 2009; Namba 1995; Niwa 2007; Sun 2008) have been employed to elucidate the control of resources, management of workers, and economic roles of urban centers in the Central Plains area during the Bronze Age and Early Imperial period. Furthermore, these craft production models clarified other issues within a broader context such as the involvement of elite sponsorship, early existence of market mechanisms, and the imperial control over standardized production. These models of craft production also provide invaluable perspectives on urbanism, labor-division, development of social inequality, and interdependence between centers and peripheries in ancient societies.

Even though the value of craft production in Chinese archaeology for understanding ancient political economy has been widely recognized, little attempt has been made to explore the iron industry in comparison with other types of craft products in the Bronze Age and Early Imperial Era such as bronze ritual vessels (Bagley 1995, 1996), bronze weapons (Shimoda 2008), and lacquerwares (Barbieri-Low 2001). Even more, very limited research has been conducted to explore the craft industries in the Han Dynasty (except Barbieri-Low 2007), especially utilizing direct evidence relevant to production process (i.e., manufacturing waste) to reconstruct the production organization and its relationship with the political system. Paradoxically, the information regarding craft production in the Han Era is not at all rare. Textual and iconographical data regarding the institutes managing production or production scenes are, in fact, very rich (e.g. Song 1992). In addition, abundant archaeological discoveries of production workshops in the capital of the Western Han Dynasty, Chang'an city, already have drawn some archaeologists' attention (Bai 2011). But the number of works using anthropological frameworks, i.e., that employing comparative study and theoretical models to represent and reconstruct the past, is still relatively low.

An important issue that is seldom addressed is how to expand the study into the dialogue with a theoretical framework to integrate the archaeological study of craft industry with its social and political backgrounds. A theoretical framework can also present a point of departure for a deeper investigation of the cultural and economic meanings of craft products. In this dissertation, I present a theoretical discussion of "commodity economies". Also, I argue this concept can provide a holistic picture of the early Chinese iron industry and serve as a platform to synthesize various lines of evidence regarding this industry from multiple disciplines. The concept can direct our focus not only on production technology but also the production organization, the social relationship between producers and consumers, and the exchange networks present in a highly centralized bureaucratic system. I will discuss the issue of commodity economies in juxtaposition with the study of archaeological indicators regarding various forms of craft specialization and market exchange, providing new understanding about the Western Han imperial economic system.

To contextualize this issue in the Han period, this dissertation focuses on the archaeological evidence related to cast iron production in the Guanzhong basin based upon fieldwork in a site complex called Taicheng. The site is located in present-day Yangling city, Shaanxi province, sitting on the north bank of the Wei River Valley. It is the first production site situated within the political heartland but outside the capital of the Western Han Dynasty that has been systematically excavated and documented. I spent two seasons in 2011 and 2012 participating in the excavation and analyzing materials including manufacturing waste, faunal remains, and ceramics, the latter two categories being are associated with workers' residential waste. In addition to the metric measurement of casting molds, samples of slags and iron artifacts from the production sites were selected for scientific analysis. These data demonstrate that foundry's specialization in the production of agricultural tools, and reinforce the significant value of the site for addressing the iron industry and commodity economy in Han times.

Two additional lines of evidence will be employed to complement the artifact analysis. First, I have collected burial information contemporary to the Western Han workshop in the same geographical area to compare the assemblages of iron products on a regional scale. Second, during the summer in 2013, I collaborated with two archaeology institutes in Shaanxi to sample iron objects from Han cemeteries to provide a technical profile of iron artifacts discovered in different loci or different contexts. This study draws upon several lines of evidence, including metallurgical analyses of manufacturing waste, metric measurement of casting molds, identification of faunal remains, spatial distribution of foundry waste, and comparisons of production techniques and assemblages found from different cemeteries in the same Basin, to reconstruct the organization and skills employed in iron production. The reconstruction of production technology and data regarding the production organization are then synthesized within the anthropological framework regarding “commodity.”

In this dissertation, I concur with economic historian Peter Termin (2013) that a model of economic structures is essential in understanding ancient polities. Models or theoretical frameworks are important as they can help piece together fragmentary evidence and reveal new aspects of data, but the results themselves are insufficient for addressing certain issues such as organization. For instance, production is the process to transform ideas into tangible items and embodies values regarding identities or social relationship (Costin 2005:1037). The employment of technology also has to do with labor divisions and organization of labor forces. To gain insight into these issues, a comprehensive study of the industry has to build upon direct evidence (e.g., various types of manufacturing waste from the iron foundry) and indirect evidence (e.g., faunal remains documenting the meat consumption of workers and iron products from cemeteries or other residential sites).

By studying iron in the context of “commodity”, the dissertation links archaeological evidence of the iron industry to its historical background. As the concept in anthropological literary is still highly debatable, the dissertation provides a thorough review of the issue. Also, I recognize that the commodity economy in a pre-capitalist setting is different from the case of modern capitalist commodity economies. Comparisons with models derived from modern Europe, I suggest, help to highlight evidence regarding iron production technology and social organization in the Han dynasty that have not been sufficiently considered before.

1.2 Significance of Research Topics

Without doubt, iron was one of the most essential products in the Han Dynasty. During the Qin-Han period (202 BCE-220 CE), the iron industry witnessed a fast-paced development associated with the emergence of influential iron merchants, and became a crucial part of the economic system (e.g. Chen 1980; Kageyama 1984; Ma 1983; Nishijima 1986; Satō 1962; Swann 1974 [1950]; Watanabe 1989; Yamada 1993). Archaeological discoveries show that after the Qin-Han period, iron objects became one type of goods frequently found at both residential sites and cemeteries. The great advance and increased economic significance of the iron industry even led to the influential "monopoly" policies established by Emperor Wu (141-87 BCE). In addition to the mining and production of iron, monopoly policies were established for other essential goods such as salt and coins in 117 BCE. These policies on iron, salt, and coin production continued to be a focus of debate in the reign of the Emperor Zhou (87-47 BCE) in 81 BCE, and was not abolished until the end of the Western Han Dynasty[1]. For this reason, the iron industry not only serves as an ideal medium for the archaeological study of commodities but also holds significant value for research on the Han economic system.

In recent decades, significant numbers of Han iron works have been found in the central plains area. Several of them have been excavated (Hebi 1994; Henan 1978; Henan 1991; Henan 1962) and provided unprecedented information regarding the structure of facilities, types of products, and other hints for understanding organization. Excavations have also yielded a large number of samples for metallurgical analyses (e.g. Chen and Han 2000; Han and Ke 2007), which are an essentially complement to our knowledge about the technological history of iron by demonstrating a wide range of techniques employed at that time. Yet, given the issues highlighted above, the exploration of the social background within which iron technology was

[1] *Hanshu* 24b.1176.

implemented in the Han Dynasty is still far less than comprehensive. How were foundries organized? How did foundries interact with the surrounding neighborhood? How were products transported? Are there any regional variations in terms of these aspects? The implications on social and economic structure from these excavations are yet to be explored.

The poor understanding of these issues is attributed to several factors. First of all, in comparison with the archaeological field-work focused on bronze foundries of the Bronze Age (Yinxu 2007; Zhongguo 2006; Zhouyuan 2004), the scale of iron works excavation has usually been limited and conducted without a systematic reconnaissance of the site. This has tremendously hampered the understanding of foundry structure as a whole. In addition, the majority of workshop data in northern China was published at least 20 years ago. These two factors to a greater or lesser degree limit the range and quality of information these data can generate. Last but not least, using reconstructed *chaîne opératoire* to understand how production was organized and fit into its political-economic context has not historically been central to most studies. Although the foundry that this dissertation is based upon is small in size and only represents one example, given the limited stage of exploration, materials from the site generate significant information that can complement our limited knowledge about iron industry in the political heartland given the fact that iron industry in the political heartland.

Before we initiate the analyses of commodities, an elaborated definition of "empire" and its implications for archaeological studies should be provided. Similar to the term "commodity", empire also covers a wide scope. In general, however, empires are distinctive from other forms of political systems by their expansive territories and the intensive management exerted over other socio-political entities controlled by them (Sinopoli 1994, 2001). These characteristics also apply to the Han Empire. Regarding its economic system, abundant records exist regarding the ubiquitous use of coined money as an exchange medium in the Han period, similar to the well-documented economic structure of other empires like Rome. The Han bamboo slips excavated in the Western frontiers against the Xiongnu at Juyan (Nagata 1989) and the contemporary mathematical book *The Nine Chapters on the Mathematical Art* (Guo 2009; Song 1994) demonstrate not only the broad range of goods that could be purchased through metal currencies but also the fluctuation of prices on products like grain according to forces of supply and demand. Archaeological discoveries of iconographic data depicting scenes of market and textual records regarding the market section (Gao 2008) also show the existence of a relatively mature market system during the period. In this sense, market exchange and commercial transaction based upon coinage are two key economic components that characterized the Han Empire. As such, the study of "commodity economies" is absolutely valid and relevant to be discussed to shed new light on the Empire.

Defining "commodity economy" in anthropological discourse is challenging, this even more so for the Han period. Although indicators of "commodity economy", such as textual data and archaeological discoveries of market, unmistakably point to the significance of market, currencies and commodities in the Han period, using this term to conceptualize the key nature of economic system is another issue. It remains debatable to what extent market exchange and "commodity economy" were playing a role in defining the nature of contemporary cities and contributing to the process of urbanism and establishment of an exchange network. Scholars like Miyasaki (1991) are skeptical of the importance of commercial function in most contemporary cities during the Warring States period, and Emura's (1995) analyses illustrate the degree of economic and exchange functions were highly varied among Warring States urban centers. Thus, the development of a market economy might have been a regionally heterogeneous process.

Emura's argument also holds true for the study of Han cities, and further complicates the debate regarding the economic function of cities and the nature of economic system. Similar to the Roman economic system which was fueled and driven by the movement of goods and fluctuation of prices, the degree of markets integration in a pre-modern setting would be divergent regionally and different from modern scenarios (Bang 2007). As the Han Empire covered a broad territory, the political dominance over economic transactions would be different from region to region.

Thus, the study focusing on the iron industry in the capital area would be of important for two reasons. First, given its special location, the study can help us understand the interaction between political management and economic production in the imperial heartland. Second, the study can also lay the ground work for future comparative studies of iron industry between centers and peripheries addressing the issue of interregional interaction. In order to better explain and understand arguments of various parties in previous debates, evidence for commodity economy during the Early Imperial China and other underlying issues will be further discussed in Chapter 3 and 4.

Using archaeological evidence to study commodities presents another challenge in the study of the Han period. Previous studies build upon textual evidence regarding markets and merchants as well as the ubiquity of certain kinds of goods in archaeological reports. But the question of what indicators reflect "commodity economy" in archaeology materials has not been fully addressed. In the dissertation, I build on previous studies explained in the section below and propose, following previous anthropological literature, that the production of commodities have to meet certain criteria regarding the techniques, organization of labor forces, and distribution pattern of archaeological materials. The discoveries at Taicheng provide a corpus of evidence in terms of manufacturing waste. The foundry itself is also adjacent to a contemporary cemetery that has been excavated and yielded a considerable amount of iron goods for comparative studies. As the foundry might have been one source of iron goods recovered from the cemetery in the same site complex (or even from other sites in the region), the site complex opens a special window to understand debates about "commodities" from the dimensions that only archaeological evidence can offer, specifically, the dimensions of production and allocation.

Therefore, this pioneering project attempts to use anthropological frameworks and archaeological studies of the iron foundry to synthesize data derived from technological analyses, archaeological evidence, as well as historical documents, to reconstruct organization of iron production. The analyses of archaeological remains in this project include several categories: manufacturing waste (e.g., slag, casting molds, etc.), faunal remains, and iron goods from adjacent cemeteries. Through this project, I will demonstrate that archaeological evidence can in fact contribute to the discussion about the nature of commodity economy in the case of the Han capital area and even more broadly the economic structure of Imperial China.

1.3 Commodities in Archaeological Studies

To fully articulate the intricate issue of commodities, I will go into detail regarding the concept of "commodity" and its applicability in archaeological contexts. Although the concept of "commodity" has quite frequently been applied in archaeological literature, it has not been as widely discussed as "specialization" or received the academic focus that it deserves. Situating the concept within a broader scholarly context with an aim to clarify the evolution of its meaning can help explain the heuristic value of the concept. The issue of commodities in previous archaeological studies will be discussed below, and a more detailed discussion about the relevant theoretical debate in anthropology will be provided in Chapter 2. The purpose of this section is two-folds. First, the review can help illustrate how the issue "commodities" has been conceptualized in archaeological literature. Second, clarification of the concept can provide a departure point for understanding its meaning in the context of anthropology, and facilitate the development of a solid approach to address this issue in the context of the Han Dynasty.

In archaeology, "commodity" is always linked to the issue of trade and exchange, two major factors contributing to the formation of complex polities (Brumfiel and Earle 1987; Earle 2002, 2010, 2011; Renfrew 2001, 2005), or interaction in more recent archaeological literature (Agbe-Davies and Bauer 2010; Dillian and White 2010). Surprisingly, its theoretical definition, research framework, applications in case studies, and, more significantly, its broader implications for other disciplines have not been fully investigated. This term has been widely used to refer to goods produced at a large-scale as well as products with a "commercial label" in previous literature, and is basically interchangeable with other concepts like trade products or exchange goods. But given the general association of the concept to economic aspects of the modern capitalist system, we need to further explore its associations and understand which aspects of ancient society can be illuminated by this concept.

It will be helpful to first look at how the concept was employed in some influential scholars' works on the title of commodities or commodification. Here I particularly focus on Timothy Earle and Colin Renfrew's works in order to describe several general methods used to study commodities in archaeological study. It is necessary to point out, however, the issue of commodities can be traced back earlier to the influential debate regarding substantial and formal economies raised by Karl Polanyi (1957, 1971) during the 1960's and 1970's. One direct product of the debate is that it triggered and inspired archaeologists from the 1960's to early 1980's to dedicate several edited volumes employing Polanyi's framework to extrapolate the mechanism of exchange in different regions (Adams 1974; Earle and Ericson 1977; Ericson and Earle 1982; Renfrew 1975; Renfrew and Shennan 1982; Sabloff and Lamberg-Karlovsky. 1975), most of these volumes are still influential today.

In one of the most widely-cited edited volumes about trade and exchange, Earle (1982) explains the purpose and methodology of study exchange and trade in the introduction, indicating his understanding about commodities. He identifies three purposes for the study of trade: 1) to source the commodities involved in exchange; 2) to describe the spatial patterning of commodities; 3) to reconstruct the organization of the prehistoric exchange. Perhaps because of the limited definition of commodities developed in his early studies, in a more recent article Earle (2002) tries to identify various types of commodities with an aim to provide an alternative explanation for the mechanism associated with different tractions. Earle claims the exchange of commodities in an ancient setting could be generally classified into two scenarios: staples and wealth exchange respectively, represented by the two cases derived from Hawaiian Chiefdom and prehistoric Denmark.

The differentiation between these two types of commodities has its own heuristic values. First, different types of commodities have distinct rates of fall-off relative to the source of production and costs of transportation and transactions (ibid, 82). Second, the two types of goods correspond to two strategies of commodity flow: cooperate and network. The former strategy is based upon the ownership of land and transportation of staple foods, while the latter is triggered through the movement of wealth, or prestige goods (ibid, 84). Using the heterogeneity of economic activities in similar political settings, Earle tries to show that specialization and commodity flows do not increase uniformly with sociocultural evolution. Nor does the amount of exchange correlate with the extent of political integration in these two cases.

Slightly different from Earle's works, Renfrew (2001, 2005) takes an evolutionary approach to articulate the significance of commodities in ancient economy and provided a more defined version of the concept. The cornerstone of Renfrew's theoretical study is that physical commodities serve primarily for exchange purposes. He defines commodities as one type of material "whose quantity may be measured, which may have a definite value, and which may be exchanged" (Renfrew 2005: 93). In other words, commodities are "exchangeable things that embody values that transactors thought are equivalent" (ibid). In addition, commodities are highly relevant to the process of social complexity as they embody material symbols (e.g., money), which play a central role by allowing the emergence and development of institutional facts that control the exchange of goods (Renfrew 2001).

From this cursory survey of these works, it seems the two influential scholars emphasize slightly different aspects in the study of commodities. Earle's focus is on the methods and purposes of studying the exchange of various types of products, which in fact are not necessarily classified or labeled as "commodities." The purpose of studying commodities lies in the desire to reconstruct the organization of exchange and cultural meanings that were transmitted and reformulated through the circulation of commodities (Earle 2010:207). On the other hand, Renfrew (2001) views commodities as more specific goods that could be exchanged by equivalences, or metal currencies, with the same value so that they could be transported long distances and exchanged on a large scale, which usually was considered the hallmark of social complexity.

I agree with Earle and Renfrew's viewpoints regarding commodities in many aspects, especially their insights on the social relationship created through consumption. But I also want to underline the heterogeneity of commodities (or commodities of wealth in particular), which can include a wide range of goods from elite-supported prestige products to mass-produced goods. To what extent can the study of commodities cooperate with archaeological study focusing on a specific type of goods? Also, it is valid to argue the flow of commodities is organized and regulated by a market system, or the forces of demand and supply, given the limitation of information exchange and transportation technology. Nevertheless, the system of markets in a pre-capitalist setting might not have been fully developed as is the case of market operation in our modern system. When a relatively broad framework and definition are employed in a historical period (e.g. Han Dynasty), to what extent will the historical characteristics of the exchange organization and its political-economic setting be overlooked by such a definition?

It will be useful also to expand the scope and look at how the concept was employed in broad-spectrum regional case studies even though they might not be as theoretically explicit as the two cases above. In the studies of the Near East (Alden 1982; Algaze 2004; Earle and Kristiansen 2010; Gilman 1991; Knapp 1985; Kohl 1987a; Sherratt and Sherratt 1989), for instance, commodity has been used widely to refer to goods that are exchanged through long-distance trade. Among these works, Rothman's (2000) study provides an interesting and potentially useful analytical tool, which derives from Appadurai's (1986) idea to define commodities as

"*any good or service that members of a society can conceive culturally as a separate class of goods having primarily intrinsic or exchange-value, as opposed to use-value, and which must* *be exchanged in an institutionalized marketplace or system of trade, often through individuals other than the primary producers of those goods or service.*" (Rothman 2000:166)

Rothman employs this concept to focus on the appearance of commodities in archaeological records. According to Rothman, the appearance of the commodity economy represents a shift of sociopolitical organization and the formation of a new institutionalized system in the Near East. One key conclusion in the paper is that elements of commodities, which in archaeology are goods of large quantity exchanged through markets, already developed in the Near East along with urbanism and the Uruk expansion, a conclusion that directly contradict to previous studies (Silver 1984; but see Lamberg-Karlovsky 1988 for a more critical review) applying Polanyi's model to against the presence of a "market economy" in the ancient Near East. Without any doubt, Rothman offers a comprehensive idea to conceptualize commodities, but I would like to contribute a discussion later (Chapter 2) to complement this framework regarding the study of production and exchange mechanism of commodities in archaeological records. The discussion would expand the heuristic value of the definition so that it can be employed to address not only the issue of the emergence of commodities but also the integration of commodities in political institutions during historical periods.

David Wengrow's (2008, 2010) recent studies of branding provide another parameter to study and identify commodities in the Near East. Instead of looking at trade or allocation pattern of goods, Wengrow resolves the issue of identification through the perspective using branding on exchangeable goods produced on a large scale (e.g. textiles, oils, a wide range of foodstuffs, and alcoholic drinks) (Wengrow 2008: 20). According to Wengrow, branding commodities, homogeneous, standardized and substitutable goods, generates very different flows of information among consumers and producers. These flows, in turn, contribute to particular sorts of trading structures and allow substitutable goods to freely circulate throughout the entire society. As the outward flow of urban products was usually accompanied by internal specialization in primary production and lengthened chains of transformation, during the transaction process, branding can help consumers identify goods that are relatively standardized and help to build up the relationship between producer and consumer. The combined use of seals and standardized packaging appeared quite broadly before the Uruk period, meeting the exact criteria for “branding,” Wengrow pushes back the emergence of commodities to the Ubaid time. Tracing the practices of branding can certainly illustrate how certain types of goods were culturally marked as commodities, but signs of branding are not the prerequisite feature. In many cases textual or iconographical evidence might not exist on commodities. The challenge of developing a comprehensive framework is still rewarding and necessary given the limitations in data.

In the New world, the concept of commodities (Earle 1985; Hirth 1998; Spence 1996; Spence, et al. 1984) also is widely employed in archaeological studies with or without the context of a market, and thus associated discussions of the concept are no less important than that those from the Old world. For instance, Spence (1996) examines the gift-commodity dichotomy to address the production of obsidians in Teotihuacan. He views commodities as counterparts of gifts. Although they both can involve long-distance exchange, commodities are goods that are more relevant to the profit-driven section of economic activities. Spence defines commodities as products that “were made by specialized craftworkers who produced quantities of them for sale or exchange beyond their own social unit, probably had little interest in the specific identities of those who purchased and used their products, and anticipated no further relationship with the consumers as a result of the transaction” (ibid: 32). Spence also views the difference between gifts and commodities to lie in the fact that gifts are inherently inalienable, which means “the identity of the donor is of paramount importance to the recipient”. (ibid: 32) Thus, in line with this idea, one essential way to identify commodities from archaeological contexts is to identify whether products have to be used exclusively for the purpose of elite ritual display instead of to satisfy the appetite of consumers. Unfortunately, as previous scholarship in the field of economic history already points out (Fine 2002), the dichotomy of gift-commodity may be “analytically ill-grounded” as the two types of goods are not always mutually exclusive. Using this dichotomy may not provide a solid base for understanding the intricacies in the definition of commodities.

It is also of interest to note that in the New World the direct evidence demonstrating the existence of markets in texts or iconography did not exist until the arrival of Spaniards. But scholars like Masson and Freidel (2012) insist that “market exchange,” one key element of a commodity economy, did evidently exist in archaeological records even prior to the post-classic period, or the appearance of standardized currencies. They argue the economic foundation of Classic Maya society was still partly grounded in the benefits of market exchange, or the realm belonging to commoners (Masson and Freidel 2012:497). Because of the intimate relationship between markets and commodities, scholars tend to be in line with Earle and argue that the concept of commodity can be loosely defined as goods that are primarily dealing with daily-life, utilitarian purposes and for large-scale exchange (e.g. Masson 2002).

The study of market-exchange in Mesoamerica has lessons to offer, such as showing that market economies often coexist with other forms of economic structures, like the knowledge-based economy (Rice 2009) or ritual economy (Wells and Davis-Slazar 2007) grounded on restricted and controlled esoteric knowledge (Feinman and Nicholas 2010:81) in many pre-capitalist contexts. Ideological and religious aspects might also be helpful to shed insight on the distinctive natures of commodities as well as some essential differences between modern and historic/prehistoric commodity economies in other social settings (e.g., Early China).

Given the significance of the topic of trade and exchange, it is impossible to list all relevant studies in various regions. But these case studies perhaps are sufficient to show how commodity – even though its definition is still ambiguous – has been widely adopted by archaeologists to conceptualize various forms of social interactions regardless of the context of currency and price fluctuation. In general, the term is usually considered to refer to goods that fulfill one of the following criteria: 1) goods that are produced on a large-scale and relatively standardized; 2) goods that are used primarily in domestic or utilitarian contexts; 3) goods that were produced for long-distance exchange; 4) goods that are counterparts of "gifts." These ideas are not completely different from Earle and Renfrew's studies, and indeed capture many social aspects of commodities. Nonetheless, adopting this general understanding does not yet address all questions.

How can we to combine these four aspects into a comprehensive framework for archaeological study? Further clarification of this concept will broaden our perspective regarding the interaction and relationship of human societies built up by the exchange of goods. Although scholars have recognized that "commodity" is not an inherent attribute of goods, which are instead defined through consumption and circulation processes (Yaeger 2010), there is still limited work dedicated to clarifying how products were circulated in order to fulfill the requirement of commodities. It is beneficial to focus on aspects of large-scale production or daily utilization in the discussion of commodities and various types of economies contributed to by the circulation of commodities (e.g. the subsistence economy, the political economy, and the ritual economy, see Earle 2010:209). We need to take another step to explain, however, the complexity of consumption context and how various parts of society would interact through the circulation or consumption process; we do not take for granted that commodities will be excluded from elite consumption contexts or that all commodities were exchanged or transported through a homogeneous mechanism.

Furthermore, besides theoretical aspects of the notion "commodity," it is also necessary to determine how to compare different indicators of commodities in archaeological records. As I explained above, commodities might cover a wide variety of products. Although Earle already proposed there are at least two types of commodities (i.e., staples and wealth), a practical framework has to allow this variation to be taken into consideration and explored through archaeological analyses of materials. Based upon Earle's classification, the study of commodities should try to explore the mechanism that organizes labor forces and technology to illustrate the social setting in which goods are produced.

Third, more often than not, a focal point of this research is the correlation between the change of commodity flows regarding their intensity, extent, and the development of political organization (e.g. Earle 2002:92). But how did exchange link various regions together? How was the network different from the expectation of that derived in a modern context? I do not reject that certain elements of commodity economies did exist in the past. Instead, I believe we should consider to what extent the exchange is different from that which would be observed in modern Europe. Taking lessons from world-system theory in archaeology studies (Chase-Dunn and Hall 1993; Hall and Chase-Dunn 1993; Hall, et al. 2010; Kohl 1987b; Stein 1999), it is clear that when applying such expansive concepts in archaeological studies, we need to discuss not only the similarity of phenomena in archaeological contexts but also how ancient cases differ from the modern ones.

Since no scholar would agree that we can directly apply the model derived from modern Europe into the past, a more productive approach is to compare archaeological cases to a theoretical model based on modern Europe and extrapolate how different sections of the society were linked through the exchange of different types of goods. This dissertation is going to take these as a departure point, by developing a theoretical discussion of "commodity" in Chapter 2, to explore a more explicit definition of "commodity" and indicators in archaeological contexts.

The commodity concept continues to generate debate in anthropology. Recently, Appadurai (1986) proposed the influential idea that gifts and commodities are only determined by different stages of the social life of an object. In other words, the same type of goods could be associated with different ontological categories according to differences of circulation and communication processes. In Chapter 2, I will attempt to address the definition and nature of commodities in the context of anthropological literature. A framework will be proposed to explain how the nature and value of commodities are generated and achieved through archaeological studies of production and consumption of iron products. These two lines of evidence can also provide clues to address how the iron industry was integrated into the political system in the heartland of the Empire.

1.4 Major Research Topics in the Dissertation

To fully extrapolate the question of commodities or the social meaning of exchange in a broader context, the structure of the dissertation will primarily be based upon an integrated and multi-scalar study of remains associated with iron production. I propose there are six primary interrelated- issues that need to be addressed. These questions include the archaeological study of manufacturing wastes and final products as well as a synthetic analysis of imperial economic structure. These questions were generally designed to articulate how technology was employed, how production was organized, how products were transported and consumed, and how these lines of evidence could be combined together to study the economic structure during a historical period.

Topic 1) *How can we synthesize a theoretical approach to commodities to provide a comprehensive framework to define and articulate the meaning of commodities?*

The sections above clearly show the heuristic value of "commodities" in archaeology. Unfortunately, this concept in anthropological literature is no less controversial. A theoretical review of "commodities" in anthropology is thus necessary in order to understand essential views of this concept and lay the foundation for studying iron commodities in archaeology. Given the characteristics of iron and iron manufacturing waste in archaeological contexts, namely, that they are highly corroded and non-recognizable, the nature of production cannot be fully addressed without a complete reconstruction of an entire production process (Topic 2) and the technical profile or characteristics of the techniques employed (Topic 3). The framework has to allow analyses of iron remains to be integrated into the reconstruction of production and foundry organization. Regarding the issue of distribution and consumption, as textual records (including excavated texts and inscriptions) are usually limited, other lines of evidence such as the variations of techniques and assemblages of products (Topic 6) have to be pulled together into a synthesis of what the exchange network looked like during the Western Han context.

Topic 2) *What are the procedures of iron production that took place during production processes? Was the foundry responsible for procedures other than melting such as refining and smelting?*

As technology is a “social phenomenon” (Lemonnier 1992:17) that must be understood through technical choices, the study of the operational sequence, or the *chaîne opératoire*, is the building block of technological studies. In this case, the basic *chaîne opératoire* of the site will be established through scientific analyses of manufacturing waste, primarily slag, iron pieces, and other production debris. A focal point of the analysis is to identify whether evidence points to procedures such as ore smelting and refining, in addition to the melting, which has already been demonstrated by the discovery of casting molds.

Topic 3) *How can we conceptualize the technical profile of the techniques employed in iron production?*

I suggest several parameters will be useful to capture the technical characteristic of iron industry. As the industry was usually organized on a large scale, the degree of heterogeneity and standardization in manufacturing waste from different features in terms of smelting, melting, mold production, and other cast iron techniques would be “proxies” to fully understand iron techniques employed. To address this issue archaeologically, variation of smelting or melting techniques across the manufacture area can be evaluated for various parameters including melting temperatures, skill of slag-iron separation, flux addition, and skill of producing molds for casting final products. In addition, an evaluation of variations regarding casting molds’ size and dimensions will be carried out to evaluate the degree of standardization and labor management of mold production within the foundry between each phase.

Topic 4) *What is the food consumption pattern of workers based upon faunal records and its relationship with the organization of production?*

Technical analyses of manufacturing remains can illustrate the issue of skills, but they also have their own shortcoming for addressing the organization of craft specialization, particularly the aspect related to intensity. I agree with Flad (2011:19) that the diversity of associated faunal remains will be a good indicator representing the degree of intensity of specialization. As animal husbandry is time-consuming and potentially detracts time from the production of other goods, the diversity of animal remains can provide hints to address whether workers engaged in full-time production of iron goods. As a considerable amount of animal bones has been recovered from the foundry, and signs of burning are not found on most bone remains, it is more likely that these are the remains of resources consumed by workers rather than the "debitage" of fuels. Therefore, this study tries to incorporate faunal remains to understand the organization of production activities at the site.

Topic 5) *Based on the reconstruction of techniques, chaîne opératoire at the site, and consumption patterns of faunal remains, what does the spatial organization of iron production look like? Which model of labor organization best matches the technical profile and degree of standardization?*

Archaeologically, different types of production organization should generate distinguishable deposition patterns of debris in terms of spatial clustering and compositional patterning (Carr 1984; Ferring 1984). Also, various degree of concentration often correspond with different degrees of standardization and patterns of food consumption. Thus, the intra-site distribution pattern of debris should illustrate the location of activities. Assuming no systematic management and off-site discard, the debris representing various procedures will reflect the concentration and segregation of various types of production activities. Besides, it is reasonable to assume that the more workers intensively engaged in the production process, the greater the degree of reliance on the neighborhood to procure meat or other food resources. In short, debris generated by different type of products or associated with different production procedures and the consumption pattern provide archaeological evidence to address the issue of organization.

Topic 6) *Where were final-products distributed according to the comparison of the assemblages and technical features of iron products from various contexts and locales? What was the mechanism underlining the exchange or distribution of iron goods within the political heartland?*

In the archaeology of the Han Dynasty, textual records concerning market exchange or internal trade-network within the Han Empire are limited, but it is still possible to make some headway on this issue. I will focus on the Guanzhong basin and compare data from burials at Taicheng, the political center (Chang'an city), and other cemeteries in terms of richness, frequency, and production techniques of their iron products. This comparison will enable me to evaluate whether the foundry preferentially targeted consumers in the nearby settlement, the Chang'an city center, or centers further away. Through the consumption pattern of final products from multiple sites, we may be able to further discuss the issue of allocation and distribution of iron goods across the political heartland.

1.5 Chapter Organization in the Dissertation

The dissertation consists of 9 chapters to articulate the theoretical issues and develop analyses of materials mentioned earlier. As this dissertation involves multiple threads and requires a synthesis of various components, here I explain the aims and purposes of each chapter.

Chapter 2 lays down the theoretical foundation for three major themes in the dissertation: commodities, craft specialization, and market exchange. Given the fact that "commodity" is a highly debatable topic in anthropological literature, the discussion has to be situated within this discourse. Various approaches to this concept in anthropology will be discussed, and a framework feasible for archaeological studies will be proposed. As I will point out later, the discussion of commodities has to be in conjunction with the production (craft specialization) and distribution (consumption) process. I will discuss how these two components can be conceptualized and integrated with the study of commodities in an archaeological context.

The historical and geological background of the iron foundry and the Han Empire will be addressed Chapter 3. Without at least a brief introduction to the economic system recorded in textual documents about the Han Empire, the discussion of the commodity issue will be shallow. Chapter 3 will summarize the structure of the Han government, economic activities managed by the government, and the "monopoly policy" on salt and iron in 117 BCE. In addition, I will also briefly outline archaeological discoveries of iron works in other regions and previous studies of iron industry in the Han period.

A brief introduction to the archaeological sequence in the region and its geological background will be given in the Chapter 4. This section will then offer a detailed introduction to discoveries in the imperial capital, Chang'an, transportation pathways, and the demographic features within the region to outline the economic and political landscape of the capital area. Archaeological works related to manufacturing waste in the Guanzhong Basin will be summarized in Chapter 4 to give readers a sense of the general pattern of the craft industry from archaeological perspective. In addition, in this chapter a brief introduction to the foundry and other sites from which I collect samples will be provided to contextualize the analyses of archaeological remains.

Chapter 5 introduces the categories of manufacturing waste that were recovered from the site. The introduction can also lay down the basic foundation for the operation and production procedures of the iron foundry. I will employ metallurgical analyses to study slag and iron pieces to better understand their physical characteristics. The study of these types of manufacturing waste primarily involves macroscopic observation, metallographic observation, and analyses of chemical components using SEM with energy-dispersive X-ray spectroscopy (SEM/EDS). After examination by optical microscope, slag, slag-like samples, and iron samples were selected and subjected to analysis using SEM/EDS to determine chemical compositions. These lines of evidence then are combined together to reconstruct the operation flow-chart of the entire iron foundry. The results of analyses show that foundry workers were relatively skillful in controlling the operation of cupola furnace and that the foundry employed not only casting but also refining and hammering to manufacture iron goods. In addition, the iron remains discovered from garbage pits were likely to be scrap iron pieces that were collected for recycling and re-melting.

Results of faunal analyses are discussed in Chapter 6. The identification of faunal data from Taicheng includes three major parts: 1) taxa and elements represented by faunal remains; 2) age profiles based on epiphysical fusion and dental eruption wear (Grant 1982); and 3) taphonomic evidence from animal bones, such as butchering marks (Lyman 1987), weathering damage (Behrensmeyer 1978), and carnivore gnaw marks. These parts are combined to evaluate whether animal remains may provide a window to understand the impacts driven by the intensification of specialization and increasing reliance on other parts of the society. The underlying assumption in this study is that people who bought or obtained their food from other members had limited options and thus follow an urban subsistence pattern, while those who bought or obtained little or no food follow a rural pattern (Christenson 1996:324). The faunal remains from the site show that workers did not raise the livestock to produce meat themselves; meat resources might have been procured through market exchange. In juxtaposition with textual records about food prices, this chapter further suggests that the workers at the Taicheng foundry might not have been convicted laborers hired by the government for craft production.

Chapter 7 addresses the organization of production. This chapter first offers spatial analyses on the site scale to understand whether the distribution of manufacturing and residential waste reflect meaningful patterns. Intra-site analysis has been explored to understand the distribution of artifacts, debris, and organization of behaviors (Carr 1984; Greenfield and Miller 2004; Hietala 1984) with an aim to identify the arrangement of activities and help reconstruct social contexts of production. The study includes the following steps: 1) identifying the garbage cleaning or other depositional factors that would impact on the assemblage of remains identified from each feature; 2) comparing the inventories of manufacturing waste and faunal remains between different features to project the location where different procedures or workers' daily activities might have taken place; 3) describing the distribution patterns of the production or waste from each production step to reconstruct production activities; 4) analyzing indicators that could allow us to explore the issues of standardization such as assembling markers on casting molds and the degree of standardization of metric measurements of molds. I argue that workers at the iron foundry might not have been organized as in modern streamlined factory in which each individual only takes charge of his own operation by following routinized instruction. Instead, mold-making workers at Taicheng were allowed to manufacture in their personalized ways. Also, mold-making workers sent their products to specific groups of casting workers; workers taking charge of different procedures might have some forms of communication and cooperation.

Chapter 8 will shift focus from the site to regional scale. I collected samples of iron objects from the Taicheng cemetery and two other contemporary cemeteries (Zhibai and Wanli). The study compares the assemblage of iron objects between the Ticheng cemetery and two other cemeteries, as well as the differences of manufacturing techniques of these three cemeteries. Furthermore, I collected a large corpus of published burial data (e.g., Han, et al. 1999; Shaanxi 2003; Xi'an & Zhengzhou 2004) and newly excavated data from the political heartland. The database is then analyzed to identify whether there is a correlation between the percentage of tombs burying iron objects in an area and their distance to Chang'an. This correlation is often viewed as an indicator of market system. By comparing the technical profiles of artifacts and their local and regional distribution, I demonstrate that residents at the Taicheng site-complex did procure a good number of iron products which were not manufactured by the nearby Taicheng foundry, probably through the market exchange. Besides, the allocation pattern of iron objects in burial contexts in the entire Guanzhong Basin supports that a market network did exist to transport a wide range of iron objects as well as raw materials to various local centers.

In chapter 9, I juxtapose archaeological data, metallurgical analyses, faunal remains, and textual information to construct an anthropological evaluation of the interaction between cast iron technology and its social setting. All lines of evidence will be synthesized to evaluate the differences between the Taicheng case study and an anthropological framework about the capitalist commodity economy derived in modern Europe. I argue that, according to the evidence related to both local production system and regional distribution system in Guanzhong, the commodity economy of iron in the Han period consisted of multiple-scale networks. On different scales, the degree of state control and market exchange varied very widely. Ultimately, my study explains how the anthropological exploration of the Han iron industry can broaden our understanding of the Han economic system. This aspect sheds new insight on addressing how the Han imperial rulership and control over its territory were achieved through the transportation of iron resources from other peripheries to the capital area.

CHAPTER 2

THEORETICAL FRAMEWORK AND KEY CONCEPTS

In anthropology, the concept of “commodity” often comes in a pair with “gift”, and this pair of concepts has been at the heart of bitter debate. This chapter first situates this pair of concepts in anthropological literature so as to identify a framework in which to articulate the issue of commodity. Two other theoretical issues, craft specialization and market exchange, will then be clarified to complement the discussion, and indicators of their various forms in archaeology will be discussed. I argue that situating the study of commodities within the discourses of craft specialization and market exchange will provide a more comprehensive and practical framework with which to contextualize iron products in the Han dynasty and understand their political and economic implications.

2.1 Concept of Commodity in Anthropology

Since the 20th century, the concept of commodity has frequently been employed in ethnographical work to characterize how an indigenous economic system is different from a market-based economic system in our modern society, and has become a crucible for debates. But much earlier than the birth of anthropology, “commodity” had already been thoroughly analyzed in the writings of classical economists such as Adam Smith (2005 [1776]), David Ricardo (2001 [1821]), and John Mill (1936 [1848]), who explicitly clarified the role of commodities as goods that embody exchange value and assumed their prices could be calculated through their labor investment or demand. Different from the classical study of commodities in political economy, anthropology contributes to the issue by showing how various forms of exchange co-exist at the same time or place and their underlying social network. In Malinowski’s milestone work, *Argonauts of the western Pacific,* “commodity” was used to demonstrate the limitation of “economic man” in explaining the *kula* exchange on the Trobriand Islands during the early 20th century. In the case of *kula* exchange, the procurement and redistribution of a series of objects serve as a key foundation to tie separated island residents together (Malinowski 1984 [1932]:351). Individuals were obligated to give more valuable counter-gifts (*yotile*) after receiving, a custom based upon a logic that is completely different from rational and self-interested calculation, and beneficial for consolidating social relationships. As the receiver cannot be a partner, there must always be in the *kula* two transactions “distinct in name, in nature and in time” (ibid: 352), which eventually functions as “glue” to reinforce the relationship of members through the exchange of gifts.

Malinowski’s study of gifts has two significant legacies. First, as is demonstrated in Mauss’s (1990 [1954]) work, gift-giving, or exchange of goods can serve as a useful lens for understanding the building-blocks of social relationship. Second, the study of gifts later fostered the dichotomy between gift and commodity and the debate between substantialist and formalist perspectives on the embeddedness of economic behavior and the degree of rational, self-interested behavior in preindustrial settings (Bohannan 1955; Cook 1966; Dalton 1978; Polanyi 1957, 1971). The former emphasizes the underlying social relationships that support economic transactions in non-Western contexts, whereas the latter draws attention to the similarities of economic systems between Western and non-Western societies overlooked by the former.

This debate also inspired economic historians like Finley (1999) to employ this dichotomy in investigating the nature of “market exchange”, which is often taken as grounded, in the classical period. Taking the dichotomous viewpoint further, Gregory (1982:12&19, 1997) draws an even sharper contrast between gifts and commodities in exchange. According to his understanding, gift-exchange involves an exchange of inalienable things that maintain an existing social relationship between individuals who are in a state of reciprocal dependence, whereas commodities-exchange involves an exchange of alienable things that maintains an existing social relationship between transactors who are in a state of reciprocal independence.

As many discussions in previous scholarship have already highlighted (Hann and Hart 2011; Wilk and Cliggett 2007), there are two essential issues inherent in the dichotomy. On the one hand, formalist approaches tend to identify "economic man" in the past or in social contexts outside modern Europe. This perspective easily loses sight of the distinctive characteristics of commodities as it defines commodity exchange as transactions of objects in a setting that would have been defined alternatively, such as "barter", according to different standards. On the other hand, the dramatization of rational market economy in a capitalist setting will fail to recognize a simple issue: "all economies are culturally constituted and embedded in larger societal contexts, albeit in different ways," (Feinman and Nicholas 2010:85)

Furthermore, it is of particular interest to note that any particular type of exchange is not necessarily mutually exclusive of another type. As Lapavitsas (2004) points out, even market economies rely on social relationships constructed through gift exchange. Moreover, various types of exchange can co-exist in the same society at any given period or place, a fact that is clearly demonstrated by archaeological studies in the Near East, Greece, and the Maya lowland (Lamberg-Karlovsky 2009; Morris 1986; Scarborough and Fred Valdez 2009). Therefore, most human societies would fall between the two parameters. For this reason, I agree with Fine (2002:48) that the conceptualized dichotomy between gift and commodity may be analytically ill-founded and may not provide a solution for articulating the intricate connection between the two concepts.

The debate about the dichotomy is further complicated by Appadurai (1986) and Kopytoff (1986) whose influential works challenge this dichotomous view. They argue commodities may represent a phase of alienability or exchangeability in the life of objects rather than an inherent and distinctive characteristic. In every society, commoditization takes place in two ways: making goods exchangeable for more and more other things, and making more and more different things more widely exchangeable (Kopytoff 1986:72). In other words, they view commoditization as a force to make more and more items exchangeable, which is different from the force of culture that prohibits something to be exchangeable. Following this conclusion, the commoditization process would result in the destructive secularization and loss of religious or sacred meaning of objects. Meanwhile, the commoditization process will also present a huge difference between modern and small-scale societies. The former are large-scale, commercialized, and monetized societies in which a sophisticated exchange technology commoditizes more objects than the latter (ibid: 87, 89). This perspective on commodities has inspired other ethnographic works to document various forms of commodities in society and social changes generated when once-alienable goods, including labor, enter into the commodity context and become exchangeable (e.g., Comaroff and Comaroff 1990; Taylor 1992).

Following Appadurai and Kopytoff, I agree with Gell (1992) and Miller (1995) that we should not over-emphasize an intrinsic distinction between commodities and other types of goods. The relationship between commodities and non-commodities (e.g., gifts) are not always clear-cut (e.g. Robbins 2009) and depends upon the context of consumption. The underlying reason is that the value of commodities, or other objects, is not an intrinsic nature determined by desires and availability. Instead, the value of objects is constructed through an exchange system (Papadopoulos and Urton 2012), which is always situated with the negotiation of a set of attributes and has to be understood within the context in which the products were produced and consumed (Flad 2012). It is basically impossible to divide goods into certain mutually exclusive categories, and the discussion about commodities has to be embedded into the political and social system in order to understand how commodities are culturally defined (Haugerud, et al. 2000:9).

Having recognized that the fluidity of the nature of commodities does not necessarily support a broader definition of commodities as any good that can be exchanged for other objects, Appadurai (1986:16) classified commodities into four groups according to the stage of their use life: commodities by destination, commodities by metamorphosis, commodities by diversion, and ex-commodities. The four terms are referred to as four types of products: products principally for exchange; products intended for other purposes that are placed into the commodity state; products placed into a commodity state though originally they were protected from it; and products retrieved from the commodity state. In the study below, I use the term commodities primarily in reference to "commodities by destination," i.e., goods that are manufactured in a particular social setting primarily for trading in market contexts, given the historical background of iron in the Han context.

In addition, I follow Fine's (2002:29) definition that "commodity exchange is always an exchange of a use value against money," which is slightly divergent from Appadurai's (1986:13) viewpoint on commodities. From my understanding, commodity exchange is different from other related concepts such as "barter exchange" – which is culturally located as a non-commercial transaction and requires no further transaction to satisfy the wants of the actors (Humphrey and Hugh-Jones 1992:5,8). Although they both require the prerequisite of being "alienable," the scale and frequency of interactions in the two types of exchange are quite different. In comparison with commodity exchange, barter exchange cannot create a stable and continuous link between different social groups and no institution is involved in setting the value of goods and maintaining the rate at which one type of goods can be exchanged for money or other goods (ibid:10).

For this reason, the commodity concept is also frequently discussed in the setting of globalization, as the movement of goods "brings together different worlds in the same space and time" (Haugerud, et al. 2000:10). This concerns not only the flow of physical goods but also information or ideas (Foster 2002:153) between various locations. Globalization also generates new consequences for consumers or those exercising power over products. This issue is well exemplified in various ethnographic work, such as the one in Tiv. In this case, the expansion of the market system not only introduces a new type of exchange medium but also expands the original exchange relationship between each member (Parry and Bloch 1989). The study of commodities, therefore, is not only a category for classification but can also contribute to forming a perspective on forces that tie various parts of society or even various regions together.

But before we attempt to apply the concept in archaeological research, it is necessary to recognize chronological changes of commodities in human history. Ben Fine, an economist and sociologist also concerned with this issue, divides commodities into two categories: simple commodities and capitalist commodities, and provides an inspiring description regarding their differentiation as follows:

"*Matters are very different in the case of simple commodity production, by which is meant independent production for the market, in the absence of wage labor. First, except in the imagination, simple commodity production cannot serve as the sole or main means of livelihood* *across society as a whole. If everyone could readily produce for the market, then everyone would produce whatever is required for own consumption. There would be little need for commodity exchange. If this is not possible because of the benefits of specialisation, then how the specialisation is created becomes the central issue, and not who produces what.*" (Fine 2002:51).

Michael Smith, a key figure in the study of ancient economy, also noticed this issue and suggests, in the setting of pre-capitalism at least, that land and labor will not be exchanged frequently as commodities (Smith 2004:78-79). In Chapter 1, my summary pointed out that archaeological studies in previous scholarship tend to trace the root or origin of commodity exchange in archaeological records even without the presence of money used as a value against other goods. Within capitalist commodities, however, products are manufactured not just for exchange but also for maximizing profits and forcing other objects, including labor, to become exchangeable. Having this distinction in mind, we should recognize that "commodity exchange" in the past would never be the same as that in modern setting. A more meaningful and valid question to ask is to which extent the "commodity exchange" presented in archaeological contexts is different from the ideal model summarized based upon the counterpart in a capitalist setting; just identifying similar elements in archaeological records does not, to a great extent, help in clarifying the nature of ancient exchange.

Therefore, the key difference between capitalist commodity economies and simple commodity economies lies in the fact that, given the circulation of goods and utilization of a monetary system, the former creates a link that transforms social relationships on a scale that is much larger and more dominant than the latter. I also want to adopt Hall's (2000) conceptualization of world-system theory to offer an analogy to this point. Hall views that within a world-system, the impacts from the core are heterogeneous about various contents, the scale of impacts, and the rate of transportation. Among the four different types of impacts: information, economy, politices, and religion, information is often transported relatively fast, while political or economic boundaries often lag far behind. Thus, more often than not, various types of impacts from the core would generate impacts reaching different extents in peripheries. Similarly, the economic impacts and other transformative impacts generated through the consumption of commodities will be more dominant and permanent in a capitalist setting. Although both types can create a network that can link the core and far-reaching peripheries, the scale and the degree of integration may be quite different between these two systems and vary case-by-case in a pre-capitalist setting.

But even the nature of capital commodities may not be homogeneous. Regarding its exchange system, Fine (2002: 82) argues "the way in which they [economic and social relations] interact may well be different across commodities. All tend to be the product of wage labor, but production processes are organized differently, products develop differently, are distributed and sold differently, are consumed and disposed of differently; they serve needs that are themselves socially constructed and satisfied (or not) very differently." Thus, he advocates a different framework–"sop" (system of provision) as an analytical tool by looking at each step of "social life" and how commodities are shaped by the cultural background.

Although I have no doubt regarding the value of "sop" for analyzing commodities, I do not think this approach would be more analytically promising than other ideas regarding the same issue, especially in archaeological contexts. In fact, an approach synthesizing various components of social life or "commodity chain" is not unique in recent scholarship at all. Carrier (2006) similarly advocates a commodity-chain model to articulate the global division and integration of labor into the world economy or an overall system by tracing every step of movement in commodities exchange. Furthermore, the emphasis on the heterogeneity of commodities should not conceal another important fact: commodities are goods that are produced by and circulated through specific mechanisms and embody special values that link various sections of society together on a large scale. This consideration provides the cornerstone of my framework to study iron production in chapters below.

In line with Appadurai's idea, the production of commodities by destination–goods that were produced principally for exchange through markets–involved specific social conditions or mechanisms that resulted in large-scale and standardized goods produced specifically for the market. This mechanism reflects the skills and techniques that are required to produce commodities by destination being much more likely to be standardized than those required for secondary or luxury commodities (Appadurai 1986:42). Building upon this framework, the project envisions that the core of commodities by destination lies in certain principles governing their production (including the organization of production, skills, labor, and standardization), consumption, and distribution. All these factors intersect with the social life of commodities and finally result in these products becoming impersonalized or alienated.

What is the lesson archaeologists should take from the discussion above? First of all, we should not conceptualize commodities as goods that always embody intrinsic characteristics different from other types of goods. In reality, commodities have many overlaps with other categories and depend upon the contexts in which the goods are produced and consumed. Second, the use of this anthropological concept is, by no means, limited to identifying elements in archaeological data. On the contrary, it has to be combined with archaeological studies of materials to understand how technology was employed to produce goods that were used primarily for exchange through market. Also, a meaningful framework in archaeology should ask to what extent the production and distribution mechanisms of “simple commodities” in a pre-capitalist context is different from the model of capitalist commodity economy. To apply this concept to conceptualize the pattern in the past, we should use capitalist commodities as a comparative reference to address how commodities– in this case iron products–serve as the link connecting dispersed people and markets.

To explain these requirements further, I believe there are several social conditions for commodities to be manufactured. First, I consider commodities as products open to members of various ranks. Elite goods (goods that are consumed only by high-rank individuals) naturally have a limited range of customers; otherwise the purchase or circulation of products cannot demonstrate the prestigious status of those who can afford. This type of goods will not be considered as “commodities by destination” in this study. Second, commodities are goods involving specific patterns of organization and relationship between producers and those who sponsor or manage the production on a large scale. Third, commodities have to be transported or exchanged through a system (i.e., market exchange) that goes beyond the direct link between producers and consumers. The circulation can therefore link segmental individuals or communities together because the value of the commodities has to be endowed eventually by circulation or consumption processes.

Employing an anthropological framework derived from Europe or a modern setting to extrapolate the nature of iron production in the Han period will naturally involve two other inter-related issues: craft specialization and market exchange. To provide a solid foundation for the discussion of the Han iron industry represented by what has been found at Taicheng, I will explain the indicators of various forms of craft specialization and market exchange in archaeology, as mentioned before. After I clarify and explain these theoretical aspects and their corresponding indicators, I will propose a framework adopted from the discussion of capitalist commodities to synthesize various lines of archaeological evidence in production and consumption sections together.

2.2 Forms of Craft Specialization and Archaeological Indicators

To facilitate the discussion below, it is necessary to differentiate several terms frequently employed in the associated literature, including specialization and organization. I agree with Costin's idea that craft specialization means "a regular, repeated provision of some commodity or service in exchange for some other" (Costin 1991:3). The production of goods that are hypothetically self-sustained and consumed only by a craftsperson himself or herself does not fulfill the requirement of craft-specialization thus defined. I also see specialization as consisting of various scenarios and, consequently, it should be conceptualized through various intersecting parameters. Regarding organization, I define it as the way workers cooperate during the production process. This cooperation can be demonstrated by the distribution of manufacturing facilities, the pattern of waste that is discarded, or by certain characteristics of final products such as the degree of standardization.

Craft specialization is often discussed in the context of social complexity (Aoyama 2001; Arnold 1987; Flad 2011; Wailes 1996, and see references therein). This topic can also be extrapolated to understand the connections between the form of specialization and the political system (Sinopoli 1988, 1994, 2003). Nonetheless, it is necessary to note that various forms of production can coexist in the same society at any given time (Hirth and Pillsbury 2013). Even the production of the same type of goods can be organized by multipleforms of organization simultaneously. Consequently, a dichotomy between social complexity and forms of specialization (Peregrine 1991) might be analytically limited since each type of organization does not necessarily correspond to a particular form of political structure.

Archaeologically, various parameters such as standardization and concentration of workers in models related to organization have been discussed (Costin 1991; Peacock 1982; Santley, et al. 1989; Sinopoli 1988; van der Leeuw 1977). Among them, Cathy Costin's paper published in 1991 is perhaps the most influential and widely cited piece of scholarly work. Costin assumed intensity, concentration, scale, and context are the four useful parameters that can describe eight different forms of craft specialization. These four parameters can be summarized as: the time engaged in the production, the distribution of producers, the requisite labor force and production area, and relationships between producers and those who control the products. The major difference between Costin's framework and others lies in the fact that Costin tries to bridge the classification on the one hand and, on the other hand, the "technical profile" of the industry including techniques, skills, and labor input. In Costin and Hagstrum's (1995) study of Inka ceramic production, they suggested eight types of organizational models corresponding to various degrees of labor investment and standardization. They envisioned that Inka ceramic workshops may fall into the categories of either a retainer workshop or nucleated corvée workshop because the production was nucleated; that products were intentionally distributed through state channels; and that products were mechanically standardized (ibid:629). In addition, the two categories are different in the sense that a retainer workshop indicates a more intensive labor investment and higher degree of skill among workers.

It is necessary to note that the understanding of these terms varies somewhat across anthrpolgical literature (Arnold and Munns 1994; Clark 1995; Clark and Parry 1990; Costin 2007; Flad 2011). Among them, the parameter "context" is usually very debatable as it concerns a pair of controversial concepts: attached and independent specialization. Costin (2007:152) in a more recent paper insisted that the distinction between the pair of concepts lies in whether elites maintain authority to exercise control over the entire production process. Production (primarily of prestige goods) supported by the state or elites is a typical example of Costin's definition. In Costin's original work and her later clarification, the term "context" refers to the context of consumption through which producers and patrons or customers are connected instead of referring to the real and physical context in which production takes place. Taking this further, Costin assumed that the difference in consumption contexts will serve as a key indicator of differences reflecting labor investment, skills, and standardization. Therefore, the involvement or not of elites or a government would generate direct impacts on other key factors contributing to various forms of specialization.

It is reasonable, therefore, to see the dichotomy of independent/attached specialization as the most essential factor necessary to classify the forms of specialization in Costin's framework. But Carla Sinopoli's case study of Vijayanagara (1988, 2003) offers an insightful example to reevaluate this essential issue and its relationship with the political system. One significant point in her work is that the degree of political involvement and centralized production does not necessarily correspond to any parameter regarding technical profiles such as skills and standardization[2]. The control over the textile industry in the Vijayanagara Empire was gradually intensified by putting workers in a centralized production center. But either technology or the scale and organization of production units changed correspondingly to increasing social demands.

[2] In Sinopoli's 1988's paper, she viewed the textile industry controlled by Vijayanagara as representing a high degree of standardization in comparison to the ceramic industry. In her 2003 publication, however, she (2003:185) suggested there is no evidence for increased textile standardization resulting from the intensification of production. Nor were master weavers, who had some ability in regulating weaving technology, widespread in the Empire. I assume that Sinopoli's viewpoint changed in the latest publication, and I primarily follow her latest ideas in this dissertation.

Regarding the exchange system, weavers maintained the practices of bringing goods to sell in the market on their own. New social needs were met through increase of worker numbers, but weavers still remained in household contexts and did not demonstrate any increase of standardization or changing of their traditional one-loom technology. In terms of these dimensions, the textile industry was not significantly divergent from the pottery industry in which political control is less dominant, and was situated in a less centralized production setting.

Dean Arnold's (2008) ethnoarchaeological study of ceramics also provides a reference to recalibrate the theoretical contents of "context." Through his case study in Ticul, Mexico, Arnold shows that the increased numbers of brokers and retailers and the development of transportation technology were the forces driving a more complex organization and an increased labor-division pattern among specialists. Although pottery production is still household–based, or the production unit-size remains the same, potters no longer control the entire sequence of production. Instead, they focus on only one of the procedures such as raw materials procurement, vessel shaping, firing, etc.

In other words, new social demands and exchange mechanisms would stimulate on the one hand the evolution of ceramic production by segmenting the tasks of the production sequence and, on the other hand, reduction of the energy inputs and increase of efficiency. Therefore, even with the same condition of political involvement or attachment, if the exchange system allows products to be more "alienable" or the social demand increases, other factors in organization such as labor division and unit time spent in each production step can still demonstrate considerable changes. In this sense, the control over "alienability" advocated by scholars (Clark 1995; Flad 2011) may better capture the meaning of "context" as a key parameter that intersects with other parameters related to organization and technology. In fact, Costin's clarification could be viewed as falling under the rubric of alienability; if elites exercise power over the entire production process, final products certainly would be exchanged and transported out of workers' hands depending on the degree of elites' control. In archaeological records, besides indicators like seals showing the presence of rulership, the allocation pattern of final products may help discern the mechanisms underlying the exchange network and the nature of alienability.

It is necessary to point out the types of evidence for articulating the issue of specialization, which can be further differentiated into two categories. The first type of evidence is directly relevant to production processes (e.g., manufacturing waste) or final products, and it can be extrapolated by the distribution of remains at workshop and the degree of standardization of final products. This set of data can be helpful for discussing the concentration and scale issues in Costin's framework. The second category is not directly relevant to production processes *per se* but still associated with the industry, such as the contexts in which products are consumed or residential remains generated by workers' daily-life. These lines of evidence will be more relevant for exploring the parameters of context and, in some cases, intensity. Costin (1991, 2001, 2005) defines the latter as the relative amount of time individual producers devote to craft production vis-a-vis other economic tasks. She envisions full-time and part-time as two distinctive extremes that correlate with skills or regularity and consistency in technique. But in the case where data regarding production manufacturing skills (e.g., the control of firing processes and the thickness of vessel walls in the case of the ceramic industry, see Flad 2011:113) or textual evidence regarding workers' daily lives do not exist, one possible line of evidence to partially address this issue would be faunal remains (Flad 2011:19), as full-time laborers, more than part-time laborers, have to rely on their neighbors who might have more time to spend on husbandry to procure meat resources to sustain themselves.

The parameter of constitution or scale in Costin's framework is inherently related to the parameter of concentration. These two parameters are the physical representation of the organization and can be addressed by evidence directly from the production site. Scale includes two interrelated meanings: the recruitment of workers into the production site and the relationship between these workers. On the one end of this parameter, workers are recruited on kin-based principles and accordingly they usually work in small and dispersed workshops. On the other extreme of this parameter, workers join the workshop as wage-labors, corvée, or are forced to participate in production as slaves. The size of this type of workshop naturally would be large and involves a more concentrated or segregated working environment.

The parameter of concentration involves two factors in Costin's study: the distance between producers and consumers as well as the degree of segregation of workers responsible for the entire production process. The two extremes of concentration, dispersed and nucleated, also correspond to the two basic types of scale or constitution. A non-kin-based workshop setting can be viewed as corresponding to nucleated concentration, while a kin-based household setting usually means a dispersed concentration. Costin argues that a higher degree of concentration and scale would necessarily contribute to a higher degree of standardization on skills or final products. Here, I suggest that labor division should be added to the parameter of concentration, which would improve the evaluation of the degree of standardization using Costin's framework. In reality, a dispersal pattern of workshops can present a relatively high degree of standardization if workers segment the entire production sequence and only focus on one specific production procedure, as is demonstrated in Arnold's ethnographical study. Without taking the pattern of labor division into consideration, segregated and nucleated workshop settings do not necessarily indicate production would be organized in a highly standardized manner or vice versa.

The clarification of Costin's terminology and their indicators in archaeological records will be beneficial for unfolding the intricacies of commodity production. It can lay down a conceptual foundation to compare the theoretical model of commodity production, conditions of the iron industry indicated by Han textual records, and archaeological reconstruction of craft specialization based upon materials from Taicheng. In this case, archaeological study of material culture regarding cast iron production can provide a unique perspective for understanding issues such as how workers were organized or how the foundry interacted or connected with other social members through the trading of goods. Given the requirement of producing large numbers of goods for market exchange, the ideal type of organization will be more likely to correspond to a non-kin-based and nucleated workshop setting. Moreover, the parameters of scale and concentration can be compellingly employed as a piece of direct evidence as long as workers are organized in a setting that emphasizes stream-lined production and standardization.

By combining the discussion of concentration and scale as well as evidence regarding residential consumption (e.g. faunal remains), the evaluation of degree of intensity (i.e., full-time vs. part-time) can shed more light on the organization itself, nature of producers or laborers, and relationships with the external social environment. This approach can eventually lay the groundwork for the issue of "context." As I mentioned earlier, the issue of alienability and exchange mechanism can redirect our focus on the factors that fundamentally determine the source of demand, labor investment, and skills in production. Although the dichotomy of attached and independent specialization cannot be explained and resolved through the evidence directly relevant to the production process (i.e., manufacturing waste), the context of consumption, intensity of labor, and organization are intimately related to one another. As

Brumfiel and Earle (1987) have already highlighted, the way that production are embedded within a society is no less important than the organization of specialization.

In short, the study of workshop organization cannot be taken apart from political involvement, relationships with other social members, the support or exchange of food, raw materials, and final products (Brumfiel and Nichols 2009:242). In this regard, I immensely agree with Costin's (1991:3) idea that the mechanism of exchange or consumption would be indispensable in the study of craft specialization. Nonetheless, how craft specialization and exchange could be marshaled to re-calibrate the issue of context has yet to be fully discussed and explained (Masson and Freidel 2013). A framework to bridge the gap between the theoretical discussion of craft specialization and distribution in archeology is necessary to address the question of commodities. The section below aims to clarify the terminology of market exchange and its archaeological indicators with the goal of developing a better understanding of the parameter of "context" and commodities in archaeological contexts.

2.3 Definition of Market Exchange and Indicators in Archeology

There are several categories in archaeology usually discussed in the study of trade and exchange: reciprocity, redistribution, and market exchange, but this section only draws focus on one set of interrelated concepts: market and marketplace. In this dissertation, "market" means the social institution of exchanges where prices or exchange equivalencies exist or forces of supply and demand are visible, balanced or negotiable, while marketplace means the physical interactions in a customary time and place where the scale of goods exchange are more intensive (Feinman and Garraty 2010). To be more specific, "a market can exist without being localized in a marketplace, but it is hard to imagine a marketplace without some sort of institutions governing exchanges."(Plattner 1989:171)

Scholars like Kenneth Hirth (e.g., Hirth and Pillsbury 2013) argue that small-scale marketplaces and balanced exchange components did exist in ancient political institutions (e.g., the Inka) even without any forms of currencies. As I will discuss later, whether market exchange can generate an allocation pattern mutually distinguishable from other forms of exchange in archaeology, such as reciprocity of gifts and redistribution—which refer to systems in which craft production principally focuses on lightweight high-value items and most households having manufactured the bulk of the goods they need–is still debatable. Without the help of textual records or evidence about "currencies", market exchange might not be easily addressed based solely on the allocation patterns of goods.

Nor should the model of "market" be viewed as an "idealization of economic activities" (Carrier 1997:31) because rational and impersonal exchange is always embedded within social relationships and does not exist independently in society. The role of taste and cultural factors that determine consumption has long been recognized in anthropological works (Douglas and Isherwood 1996). Even in the case of contemporary global commodity chains, demand and supply are not the only two factors driving the flow of goods and establishment of social network (Gereffi, et al. 1994). Again, since market exchange is embedded within the cultural context in capitalism (Feinman and Nicholas 2010; Granovetter 1985), it adjusts according to the external political, economic, social, and environment context in which it is situated (Bestor 2004:292). For this reason, archaeological research on a specific type of goods—the study of their social life involving production, distribution, and consumption—can profoundly contribute to studying the social meaning or value of commodities even in the period when textual records regarding market exchange or commodities are already abundant. The variation of consumption patterns between different communities can provide insight on the social connection established through communication, which is always, to a certain extent, different from the theoretical model.

Various approaches have been proposed to identify markets (or marketplaces) from archaeological records. As direct evidence of markets in texts or iconography is always rare, focus has been placed instead on the patterns of consumption preserved in archaeological material. In addition to applying theories like Central Place Theory to explain how markets determined the distribution of ancient settlements (Blanton 1996; Smith 1978), other approaches, including institutional (Dahlin, et al. 2007), spatial (Hodder 1977; Hodder and Orton 1976; Renfrew 1975, 1977), and distributional (Hirth 1998) approaches have been dedicated to identifying traces of market exchange in archaeological contexts, particularly in periods without textual records about economic exchange or the existence of the market.

But each approach has problems that complicate the applications in archaeological contexts. For instance, geographical approaches using "Central Place Theory" assumes the settlement pattern should serve as a good indicator of marketplaces (Christaller 1966; Smith 1976; Smith 1974a, b). In the distribution of settlements, centers might match the theoretical pattern to maximize efficiency and reduce transportation costs (Blanton 1976, 1996). The downfall of this model in archaeology is that its application usually does not take equifinality into consideration and requires a large pool of settlement data (Stark and Garraty 2010:38). Institutional approaches attempt to identify the location of marketplace physically through the comparison of chemical composition of soil and alignment of features—which might not be easily identifiable—from modern markets and archaeological sites. The spatial pattern approach focuses on the relationship between frequencies of goods and distance between sites at which goods were found.

This approach assumes correlation patterns of these two factors represent various exchange or trade models. For instance, in the case of market exchange, the frequency of goods will not decrease along with the increase of distance between sites and production centers because of the redistribution function of the market. Archaeologically, the spatial pattern approach can be more practical than the other two approaches mentioned since it does not rely heavily on intensive survey data and the identification of a potential marketplace at a site. But a comprehensive study still has to further take equifinality and consumption contexts into consideration.

Hirth's "distribution approach"–which draws on extensive studies of market exchange in Central Mexico–is based on the same theoretical foundation assuming the frequency of goods across a region can indicate various forms of exchange systems. Where it diverges from the spatial approach, Hirth's approach focuses on the similarity and diversity of assemblages between elite and commoners' contexts (primarily households) on a regional scale. Specifically, Hirth's approach assumes that conditions of market exchange have to include: 1) production of goods (primarily portable goods) on a large scale; 2) social members having equal access to the products; 3) an inventory of products over a broad area that is not determined or predicted by a gravity model.

In archaeological records, the three conditions of market exchange would generate a pattern divergent from redistribution or reciprocity because of the high frequency and intensity of objects exchanged in this mechanism. Hirth's distribution approach (1998, 2010) draws attention to the distribution of craft goods across various kinds of contexts, especially households. He suggested the result of marketplace-exchange, the most centralized and efficient form of market exchange, is "an increase in the homogeneity of material culture assemblages between households of different social ranks." (Hirth 1998:456) To put it in a more simple way, if the same range of low-cost utilitarian goods is found in households of both low and high ranks, the allocation pattern indicates resources flow primarily through independent economic channels, or marketplace exchange, rather than through other hierarchical, state-controlled redistribution networks.

The most significant and distinctive feature of market exchange, according to Hirth and others following his approach, is its exclusiveness from any “social ties” (Stark and Garraty 2010: 42). This approach views the domain of commodity exchange as completely outside the control of any state, government, or elites; exchanges that involve upper-rank members belong to command economies, centralized redistribution, or both. These mechanisms generate the allocation pattern of goods different from market exchange, as the volume, diversity, efficiency, and distance of goods moving through the distribution system of market would be much higher and more visible. Since there is only one type of market exchange conceptualized in the study, I view this approach as a narrow definition of market exchange in archaeology.

On the other hand, scholars like Minc (2006) conceptualize market exchange more broadly and diversely. Drawing on a heuristic model developed in a case study of Aztec market economy, Minc proposed four major types of market exchange: solar, overlapping, dendritic, and integrated, which can be conceptualized by four parameters: scale, network, hierarchy, and political congruence. These four types reflect different degrees of hierarchy and network connections between “market centers” and “market zones.” Solar and overlapping systems exist in separate market territories that are non-hierarchically inter-connected. These two models differ according to whether the territories are constrained by political boundaries.

Dendritic and integrated models, in contrast, happen within a hierarchical setting. Their difference relies on the degree of network development and the control over production and exchange by a primate center. Dendritic markets involve communities integrated into a regional system dependent upon a distant primate center, typically similar to the idea of central-place exchange systems (Christaller 1966; Smith 1974a). Furthermore, in the periphery, locally produced goods will predominate relative to centrally produced goods (Minc 2006:86). The integrated model is equivalent to Hirth's market exchange framework that assumes an assemblage will be more homogeneous between different contexts or centers of different ranks due to the forces of market exchange. In my case study, particular attention will be given to these two models.

Minc's framework is different from Hirth's approach in three ways. First, the former better takes "political involvement" into consideration. In an earlier section, I explained it is theoretically impossible to imagine market exchange entirely independent from any political institutions or involvement. Meanwhile, political independence or merchandise behavior alone does not define the characteristic of market exchange. The classification, therefore, is more solidly grounded on the reality of society.

Second, market exchange usually covers a wide range of scenarios. The distance goods travel varies and the degree of market reliance ranges along a continuum, with an integrated market that relies heavily on market channels on one end, to a peripheral market through which only a limited number of commodities are exchanged on the other (Stark and Garraty 2010:53). Hirth's approach only targets one specific type of exchange, but Minc's framework can be used flexibly to describe varieties of market exchange.

Third, Minc's "market exchange" framework focuses on the relationship between a market center and market zones. It is of interest that Minc defined "market system" as a mechanism that coordinates resources mobilized from producers and households to provision themselves with needed items (Minc 2006: 83). This definition does not entirely exclude market exchange from other forms of exchange (i.e., redistribution or command economies) but still allows us to capture the variables that interest archaeologists the most, such as the relationship between production centers and consumers, transportation pathways, the degree of integration, as well as the distance to and boundaries of interaction zones created by good circulation. That said, Minc's approach is more likely to reconcile the issue of equifinality, such as certain cases of redistribution that are not obviously distinguishable from the market exchange controlled by a centralized government in archaeological records, and provides a useful framework to articulate the relationship between political and economic domains.

In terms of applicability in an archaeological case study, Minc's approach also allows a more contextualized synthetic study for the following reasons. First, with very few exceptions in human history, elements of markets (the place of trading or long-distance commercial activities) are undoubtedly and ubiquitously documented in various historical records during historical or imperial periods. Obviously it will be redundant to frame a question that only aims to identify the existence of market exchange. A more profitable framework should look forward to providing more variables to explain how other factors are involved in economic transactions. The second issue is closely relevant to Fine's comment (2002:51) on "simple-commodity exchange" that an interest-driving economic system based relatively on the assumption of "economic men" did not take shape until the arrival of capitalism. Even if the connection between assemblages and a "market" exchange model holds true, it is reasonable to expect that, more often than not, patterns of assemblages across a region will be heterogeneous to a certain extent and thus, other parameters are required in order to provide an alternative explanation instead of the presence or not of market exchange. Minc's framework can facilitate the investigation of various market exchange systems and shed light on the economic system in a pre-capitalism setting through a comparison study with modern exchange systems.

Identifying the core or source of production is one of the prerequisites in both Hirth's and Minc's studies. The discovery of Taicheng, therefore, provides an excellent set of data to discuss the distribution of iron in the region as one of the potential sources of iron goods. In this project, I combine Hirth's distribution approach with Minc's four theoretical frameworks by focusing on the allocation patterns of objects from cemetery contexts to see if the relationship between the frequencies of iron and distance to potential production centers can match one of the scenarios.

But the market in the Han dynasty might not be the same as the concept "market economies" anticipated, as the government was heavily involved in economic transactions. Although textual records can provide a broad description regarding the governing of goods movement in the capital area, it is reasonable to assume the Chang'an city area might have served as a production and exchange center transporting goods to other lower-level territories like Taicheng, given the significant political role and large population (Ge 1996) of Chang'an. My strategy, therefore, is to divide the distribution study into local and regional scales. Given the fact that production remains within the great metropolitan area are not always nucleated, a central question is to further determine if final products were used by individuals in the same community, or transported to far-flung areas through a market system. At the local scale, the study will consider whether products are primarily targeted towards adjacent neighborhoods by comparing data from the foundry and objects from adjacent cemeteries.

At the regional scale, the exploration aims to determine the mechanism of exchange across the political heartland and to identify to what extent market forces were playing a role in the allocation of products. The techniques and assemblages are compared between different sites in Chapter 8 in order to understand how the allocation pattern would be different from our expected model. If the dendritic model holds, we should expect to find that assemblages of iron goods from the core represent a wider range of types than in the periphery. The frequency of certain types will also be much higher, indicating the exchange of goods relied more heavily on political and administrative forces. In contrast, if the integrated model—the full-fledged form of market exchange—is more accurate, we should witness similar assemblages and richness of iron products between the political center and lower-level settlements.

2.4 Strategies of Identifying Commodities in Archaeological Records

Table 2.1 Summary of Carrier's framework that conceptualizes the elements of commodity economy

Aspects	Details of transformation in the late 17th century
Location	Moving to a central place; separation of industrial areas from residential ones
Tools	Workers are less likely to own their own tools
Identity	Workers were treated as impersonal laborers
Organization	Increased division of labor; breaking-down of production into more and simpler steps; each step was routinized
Exchange	Market exchange took over; buying transactions became impersonalized

With these considerations in mind, an integrated framework that can bring together these various components can be adopted from James Carrier's (1995) work. In his study entitled *Gifts and Commodities*, Carrier tries to depict how the development of the commodity economy reflected and represented a spectrum of social variables including production location, ownership of tools, workers' identity, production organization, and the market exchange of final products after the late 17th century in Europe (Table 2.1).

In juxtaposing the Taicheng case with Carrier's stimulating studies of capitalist commodities derived from the formation of commodity economies in Europe, I evaluate several criteria that can help identify characteristics of "alienability", the most determined factor of commodities, in archaeological contexts: 1) whether manufacturing areas were located in a central place distinct from a household setting; 2) whether manufacturing became more intensive and, if so, whether workers had to spend more to buy what they could no longer make for themselves since less labor was available for subsistence production; 3) whether workers converted to routine operations, and production techniques were standardized to increase efficiency and reduce workers' artisan abilities; 4) whether there was a high degree of labor division and an assembly line-styled break-down of the production processes; and 5) whether a market system was in charge of the transportation and distribution of final products, because commoditization is always accompanied with an immoral economy which de-emphasizes the significance of personal relationship with traders. Although the first criterion is relatively easy to evaluate in the case of Taicheng as excavation shows that the foundry is apparently a nucleated production site, other frameworks discussed below will assess to what extent Taicheng's scenarios are different from the characteristics of modern commodity economies based on analyses of remains from the foundries or adjacent sites. Eventually, all analyses below will try to illustrate how patterns in the production and distribution of iron commodities define the market economy in the Han setting.

In textual references, iron foundries controlled by the Han government after the implementation of monopoly policy might have been categorized as either a retainer workshop or nucleated corvée workshop (Barbieri-Low 2007:236, and see discussion in Chapter 6). It is uncertain if this was the case with Taicheng; but a high degree of standardization resulting from nucleated production (Flad 2011:21) at a production site is one of the defining features of a retainer workshop or corvée workshop (Costin and Hagstrum 1995). Therefore, if analyses demonstrate the organization of Taicheng resembles the theoretical model of a concentrated workshop employing corvée, retainers, or non kin-based workers concentrated in one place to engage in full-time production activities, it is valid to consider Taicheng as a commodities-targeted production site associated with a state. In the case of Taicheng, the historical backgrounds and archaeological contexts have already alluded to significant information regarding craft specialization. For instance, the excavations at Taicheng exposed considerable amounts of nucleated debris and casting moulds of similar forms. In order to test this archaeologically, the production techniques (e.g., smelting or melting and moulds production techniques) reflected by manufacturing waste should be relatively standardized and homogenous, which is related to the third criteria mentioned above. My study of manufacturing waste through metallographic study in Chapter 5 will identify the techniques employed in production and the degree of heterogeneity regarding iron techniques.

In order to further address the issue of intensity, in Chapter 6, I will employ faunal data to evaluate if the meat consumption patterns reflected that workers heavily relied on exchange with neighbors instead of a self-sustaining system. Additionally, we should expect that laborers were divided to specialize in each procedure in order to stream-line production. Building on the reconstruction of techniques, the intra-site distribution pattern of debris and manufacturing waste might map out where various production sequences were situated across the site or even how labor was organized. In Chapter 5, I will first analyze the techniques of manufacturing waste.

Then in Chapter 7, I will compare the assemblages of products, manufacturing waste, and other remains (e.g., faunal remains) to illustrate the patterns of distribution across the entire iron foundry. My null hypothesis is that, if the production techniques and residential waste demonstrate a high level of standardization, stream-lined production sequence, and relatively intensive specialization, the concept of commodities by destination will be appropriate at least to describe the production system in this case study.

Regarding the issue of distribution and transportation, I expect that in the case of a commodity workshop, most products were produced for exchange through the market system. The major indicators that allow us to draw connections between the location of production and consumption are indirect lines of evidence, such as techniques and assemblages. For instance, if Taicheng supplied the majority of iron products to its neighbors, the assemblage and perhaps techniques reflected by iron objects from the foundry should correspond to those found in the cemetery. Furthermore, if market exchange was the primary method of distribution, and connected production centers and consumers, the assemblages of products that were made with similar techniques would be relatively similar between Chang'an and lower-rank settlements (e.g., Taicheng). If so, the ubiquity or discovery rate of daily-used iron objects found in archaeological contexts from different locations would also be relatively similar. In Chapter 8, I will illustrate the regional variation in terms of technique and assemblages based on the analyses of iron objects and published burial data from different locations. These two lines of evidence can serve as two indicators to evaluate if the distribution and exchange were determined by the political hierarchy or market exchange forces.

In Chapter 9, these various analyses will be synthesized together to elucidate the patterns of iron production and transportation in the Han capital area. Eventually, these patterns can lay a solid foundation to address the key issue in this study: to what extent is the production and transportation of commodities (e.g., iron objects) similar or different from the mechanism of commodity economy in modern society? Taking these multi-methodological approaches will be beneficial not only to resolving the debate about the economic system in the Han period, which will be explained in detail in Chapter 4, but also to addressing similar questions related to craft production in other regions. One typical example that is closely relevant to this case study is the relationship between the organization of production and rulership in the Japanese iron industry (Anma 2007; Murakami 2007). It is worthwhile to explain this point at some length before I close this chapter.

According to the typological study of workshop layout and structures of furnaces during the Atsuka period (the 6^{th} to 8^{th} century CE), scholars like Takumi Anma (2007) suggest that workshops in the *kinai* (capital) area that were directly controlled by the centralized government were different from workshops in provinces that were controlled by local governments. Japanese scholars usually focus on the parameters of specialization[3] and mobility to illustrate such central-regional differences: workers in the capital area tended to skillfully construct furnaces that could be used only in iron production, indicating smiths might spend a longer time in iron production during a year vis-a-vis other activities. On the contrary, workers in regional workshops showed lower degrees of specialization and were smaller in size. Furnaces at these types of workshops were less skillfully constructed, and products that might come from these workshops were also less standardized. Thus, these two types of evidence indicate that the political control over production in the center was much more intense than that over regional workshops.

[3] From my understanding, the term "specialization" in Anma's work, in fact, refers to the intensity and constitution parameters in Costin's framework.

Although the studies of Japanese cases are insightful and provide comparative cases within which to articulate the issue of governmental involvement, the framework that I propose in the study to analyze remains from Taicheng and information from the capital area can, in fact, complement previous research on iron or bronze craft production by expanding the discussions into two new dimensions. First, more often than not, workers or their community were always ignored in the study of this topic, but information like subsistence is an indispensable line of evidence to address the issue of organization. Second, the integration of the analyses of organization and transportation system is still a subject that is poorly understood. As I mentioned earlier, a better understanding of relationships between political control and production requires a comprehensive investigation of the range of skills and techniques represented by tools and manufacturing waste, the organization of laborers, and goods transportation or distribution systems. Using the concept of commodity and a framework to incorporate the study of techniques through scientific analyses, exploration of intensity through analyses of faunal remains or materials indicating other production activities, and regional comparison of objects, can hold promise of exploring new approaches in the study of craft production within the broad context of a complex political system.

CHAPTER 3

NATURE OF HAN COMMERCIAL SYSTEM AND IRON INDUSTRY

Introduction

Iron was unquestionably a type of essential commodity the Han period. The manufacture of iron goods required specialized knowledge and was very difficult for every village or community to make their own iron tools. The procurement of iron must have relied on other craft specialists and an exchange network. Iron goods are durable and portable through long-distance exchange. Meanwhile, it was a special type of commodity that was involved in various forms of governmental control and therefore serves as an ideal case to investigate the political significance and involvement in the concept of commodity.

An application of the commodity framework in the Han period needs to clarify a core question in the beginning: the historical contexts in the Han period. The economy of the Western Han Empire (206 BCE to 9 CE) is often understood through a top-down perspective regarding the impact of polices promoting agriculture, implementing monopolies over salt, iron and coin minting, controlling standardized weights measures, and stabilizing the price of goods (e.g., Loewe 1985, 2006; Nishijima 1986; Scheidel 2009; Yamada 1993). Also, there has already been voluminous debate regarding how the "commodity economy" would fit into the historical discourse on the Han history. But studies focusing on the market system in a specific region are still relatively limited. Ideas about the significance of the commodity economy in the Han economic system, therefore, have been widely diverse. To unpack the complexity of the relationship between the commodity economy and the Han financial system, this chapter will first review debates about the Han commodity economy and explain how the issue was conceptualized. Just like the discussion about commodities in anthropology and archaeology, this term has been employed in many ways in the literature. Clarification of this term is necessary to lay down the foundation for improving the understanding of the issue in Han history.

Furthermore, whereas theoretical debates have already summarized various aspects of the market system recorded in textual records, and thereby provide a solid foundation for the discussion, the issue in the study of commodity economy of Han history often overlooks the fact that the Han commodity network—just like other market systems in ancient contexts—did not create a homogeneously integrated market system; small markets and settlements might not have been integrated into an unified imperial financial system because of limitations in transportation and traffic technology. Discussion about ancient market also needs to take types of commodities into consideration since their allocation patterns and transportation system may also demonstrate certain degrees of variation.

To continue the discussion about the commodity economy of iron in the Han period, this chapter will briefly introduce the organization system of the Han government, with a special focus on the management and control over either the iron industry or iron objects. Iron objects became indispensable necessities in the Han period and became a type of profitable resource throughout the entire Han Empire. But commodities were never separated from the control of the central government and never developed into a private domain without government involvement, even before the implementation of iron and salt monopolies after 117 BCE. Since Chapter 8 will address the allocation and distribution of iron goods in the entire Guanzhong Basin, I will discuss here how the production and consumption of iron goods would be integrated into the central and local system of the imperial economy from textual records to provide background and context for later discussion. In section 3.2, I will also explain details about the monopoly policies in order to identify the potential impacts imposed by the banning of “private craft industry”.

The importance of iron in the imperial economy indicates that the Han government developed a complicated system to manage and exploit the iron industry. But textual records seldom mention aspects of the iron foundry operation in detail. This is the major reason archaeological evidence plays a critical role in a detailed understanding of this issue. The last section introduces the Han iron foundries primarily in present-day Henan and Shandong Provinces that have been found and excavated and summarizes certain characteristics in their organization. The review of these aspects can help demonstrate how the Han government achieved its control over the iron industry. Consequently, the discussion provides an additional aspect from archaeological contexts to complement to the limitations in textual records by providing “blueprints” for guiding the reconstruction of the *chaîne opératoire* of the case study in Chapter 5 and the production activities in Chapter 7.

3.1 Issues and Debates about the Commodity Economy in the Context of Han History

As the issue of commodities intimately intersects with Han economic history, in this section I try to articulate its meanings in the discourse and debates in the literature. In particular, I attempt to identify the relevance of this debate and the theoretical schemes discussed in Chapter 1 and 2.

In historical texts, records of market exchange are extremely pervasive and almost countless[4], which inarguably suggests the ubiquity and significance of private merchants and

[4] For instance, there were at least nine markets in the Chang’an capital in accordance to *Sanfu huangdu* 三辅黄图, “there was nine markets in Chang’an, and the length of each one was 260 bu…..There were Liu market, Dong market, and Xi market. Each one had office in *Shiliu* to monitor transaction and commercial activities.” (*Sanfu huangdu* “长安九市 Chang’an jiushi” 2.93; see references related to the issue in Kamiya 1994). In addition,

market economies during this period. Even in local county-level towns, markets were also established to facilitate the exchange of products (Gao 2008:109-111). As a result, managing the local markets and standards of goods sold there even became one major duty of governors in counties (*xianling* 县令)[5]. In the Han period, market networks not only transported goods between large centers but also extended towards rural areas to provide goods through the network that did not exist before.

Besides the existence of the market, the coinage system during the Han period was highly advanced (Scheidel 2009) because of the development of commercial economy. The government not only manufactured substantial amounts of coins but also adjusted the inflation of price through setting up new standards and minting new types of coins[6]. Most types of products were exchanged based on the coinage (commercial exchange) instead of in kind exchange. Furthermore, farmers who received pieces of redistributed land from the government were subjected to labor tributes, good tributes, and even the cost for transporting these tributes or taxes to the destination (Li 1957:144-145; Watananbe 1989; Shigechika 1999). Corvée labors were also a form of taxes in the Han period, and labors would be hired for serving the labor tributes for others. During the Han period, a wide range of goods and even human labors were commoditized[7] and could be transacted through the market system (Li and Ma 2011).

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excavated textual evidence about a market or marketing managing institutes, namely shi or ting, are also voluminous. See Yu Weichao (1984).

[5] *Shuihudi* "Statutes on currency", trans. Hulsewe 1985: 53, A46.

[6] *Shiji* 30.1419, 1425-1429. *Hanshu* 24b 1152-1153, 1163-1165.

[7] During the Han period, labors could be hired to work for a wide range of duties and work and a "market" for the selling of labor did exist. See Ma 2012 and references therein.

As these aspects are tightly linked to commercial economies, previous scholarship hardly disputes the commercial transactions and the market economy during the Western Han or even the Qin era developed rapidly and even reached one of its peaks in Chinese history (e.g., Fu 1982). Since iron tools were widely used and replaced other materials for the manufacture of agricultural implements, the commodification of iron and its market system provided invaluable opportunities for merchants such as Guo Zong 郭纵[8] to accumulate wealth through iron smelting and selling of iron goods (Li 1957:178) during the Warring States period. Although the legalists were well-known for policies of restricting merchants in terms of their social and economic influence, the development of a commodities economy (i.e., exchange based upon a coinage system used to exchange goods through market) should not be deemphasized. As many scholars have argued (e.g., Si 2002; Yates 2002), the Qin government was extensively involved in all economic activities, and those commodity exchanges managed by the Qin state achieved development to a certain extent. Coinage system and management rules of the market were also becoming more complicated or standardized during this period and continued to be adopted by the Western Han period.

As records regarding the acquisition or purchase of a wide-range of daily-use products through the market-system are ubiquitous, scholarship in Chinese that is substantially influenced by Marxist study of ancient economic models encounters a dilemma if the "commodity economy" (i.e., that is the economic system is purely based on the market exchange of commodities) played a significant role in the Han economic system, and even more importantly, if the term "feudalist economy" (i.e., that is more based on kind-exchange) adopted from Marx's works was applicable to the context of the Western Han dynasty (Deng 1994). The debate about the ancient commodity

[8] *Shiji* 129. 3259.

economy also drew scholalry attention to the nature craft industry (e.g., state-owned versus private-owned) in ancient China. Since the 1930's, the study of Qin-Han craft industry (e.g., Chen 2007 [1936]; Satō 1962; Tong 2008 [1981]) always emphasized the emergence of private industry (i.e., goods that were produced primarily by commoners) and the differentiation between private and official industries as the hallmark of the commodity economy. This issue of commodity economy also involves the long academic debate about "economic patterns" and the so-called "chronology of ancient history" (Li and Zhang 1999) in pre-modern China, which generated even more voluminous references to this issue especially during the 1970's and 90's. As I will point out later, this long and influencial debate, in fact, is more or less in line with the substantialist-formalist debate in the economic anthropology; both sides focus on different aspects of the ancient economic system but talked past the other side.

To be more specific, the ideas surrounding this debate about the Han commodities economy could be briefly divided into three categories. The first side (e.g., Fu 1982) tends to view the commodity economy in the Han period as primitive and not fully developed. Also, the entire social-economic system still had been dominated by natural economies (i.e., production usually focused on self-support). Although they agree that private mining, salt evaporating, and copper minting were operated by private workshops and that these activities became profitable during the short period of the Han, the monopoly policies cut short the life of this preliminary commodity economy (ibid: 343). When the government monopolized the iron and salt industries, the production and distribution did not follow the pattern of market economies anymore. In other words, craft products, including iron, were not manufactured specifically for "market exchange", or at least following the mechanism of the market system. For this reason, the economic system during the Qin-Han periods still belonged to the so-called "feudalist economy" (Li 2001) based upon the dominant agriculture production and driven by the relationship between landlords and peasants.

The other side of the debate (Deng 1994; Gao 2008; Leng 2002a, b; Zhang 2003), however, views the elements in the commodity economy as being more fully developed given the wide range of the products (i.e., exotic goods) traded through the market system. Even in the domain of the natural economy, namely the exchange of staple foods, meats, and vegetables, they tend to view the exchange of the commodities as being highly developed alongside the urban development which was witnessed throughout the entire Qin-Han period. Moreover, a "regional market", i.e., one in which a large-scale market connects different geological regions, became relatively developed (Chen 2005) in the Han period. In accordance with this side, "commodity economy" should be the major element that evidently contributed to the overall Han economic system.

Similar to debate between formalists and substantialists in anthropology, certain scholars were positioned in a middle ground position between the two sides and try to use a compromised framework to reconcile the two positions. Huang Jinyan (2003, 2005), for instance, argues that market or commercial economies in which products were only used for exchange were developed in the Han period, but this does not mean a widespread of commodities controlled by market rules. This is especially true in terms of the macro-scale environment; a uniformed and national market did not form during this period, and the development of each region was not balanced. These scholars attempt to carefully cast a balanced role between exchange economies and peasant economies (or natural economies) during the Warring States and Qin-Han periods. While they view that a wide range of goods would be exchanged through the market, they also cast doubts on a large and national market network in the Han period (He 2001a, b; Lin 1997, 1999).

No matter which form or framework each side has employed, all agree on one basic common ground, which is, at least by the Late Warring States period, iron, salt, and other necessities had already become commoditized and purchasable through the market system. The core of this debate, therefore, is not whether the commodity economy existed in the Warring States and Han or not. Rather, as I explained in Chapter 2 using Fine's perspective, the most fundamental disagreement among these scholars is the conceptualization of the extent to which a full-fledged market economy formed within the large Han territory. Commodities in the Han period include almost everything used in daily life, but they were manufactured based on different types of models. For instance, the textile industry might be more associated with a self-support model in which the production focused on meeting household needs first and would be manufactured in a household-setting (Li 1957:157). But in terms of the iron and salt industries this was not the case; these items were produced just for exchange. This is also a major contribution of the case study that I am going to introduce below as it can provide a new perspective to investigate this thorny issue.

Even though many items, including iron, were classified as "commodities", the definition of this term in the historical study of the Qin—Han period is different from the definition discussed above in several ways. First, the distinction is made based on the type of consumers; goods that were produced for commoners' needs are called "commodities" in general (e.g., Satō 1962), which is not directly relevant to the way goods were produced or distributed. Second, the context of "iron commodities" is also discussed within the involvement of the Han government, which recognizes the distribution or transportation of this type of products was not entirely determined by a “market”. Lastly, textual records prefer to project that the iron industry during the Han period was conducted on an “industrial” scale, as many of the production procedures involved knowledge and techniques that commoners could not handle, while research often overlooks the fact that iron production would be conducted in a small family-run factory setting.

Along with the development of a trade network, commodities became an iconic term in literature to characterize the nature of economic activities and attracted attention from historians. Meanwhile, scholars recognize the degree of commoditization would vary across different types of products. For instance, the degree of commoditization among agricultural products might not be very high (Huang 2003). For most residents living outside intensive urban centers, products were available to various degrees in the market and perhaps generated various distribution patterns in archaeological evidence. In addition, Emura Haruki (2000, 2011), one of the most distinctive scholars in this area, emphasizes that this type of “mosaic” pattern reflects not only the mixture of different types of economic systems but also regional variations in urban development. According to textual analysis, the development of a commodities economy and market exchange in urban centers in the Central Plains appears to be much more advanced and full-shaped than in the Guanzhong Basin during the Warring States period, even though the basic elements such as the market and coinage system was adopted in the the Early (387 BCE) and Middle Warring States period (336 BCE)[9] respectively. The Warring States and Qin-Han period was by no means entirely dominated by a “commodities economy” as conceptualized by several scholars in the early study of Early China’s economic system (e.g., Utsunomiya 1967). Thus, this study of commodities below will also focus on the interregional variations reflected in archaeological materials.

[9] *Shiji* 6.289.

From this brief review of textual records regarding the issue of the commodity economy emerges a mixed image of the Qin-Han period, and each side of the debate could, in fact, find supportive evidence for its viewpoint. One major reason is that in texts quantitative evidence showing to which extent commodity economies were embedded or dominated the economic structure does not exist. In addition, the model adopted in previous studies about the comparative counterpart, for instance the economic system of Medieval Europe, is often unclearly defined. Although some studies tend to view the agrarian economy as strongly merchandised insofar as individual farmers were knitted into the commodity economic network (Hsu 1980:153; Kakinuma 2011; Li 2012), the extent to which commercial activities dominated state economies, and how different levels of local administrative units, especially hamlets or small villages, were integrated into the imperial economic system through buying and selling goods at market, are issues open to debate (Bang 2009; Lin 1999). For this reason, iron, given its significance in both state finance and the market economy, is the ideal type of commodity that would generate useful information to solve the dichotomy in the study of the history of economy. It is necessary to point out that the debate mentioned in texts primarily focused on social impacts and influence caused by the monopoly policy. In all of this literature, the question of how the iron industry was organized—which is the key question that we are interested here—has seldom been touched on in the conversation.

Having reviewed the debates of the theoretical concepts, it seems that an archaeological perspective adds several new perspectives to the debate about commodities. Archaeological data show specific techniques employed in the production of large amounts of goods. Through the reconstruction, the study can provide a better sense of social demands and the mechanisms of supply in a specific regional setting. Archaeological study can also help address specific allocation and distribution patterns within a specific region, which becomes an essential piece of information for addressing the scope and scale of the national commodity market. In addition, all sides in the debate are aware of the governmental involvement in the production of craft products (in particular salt and iron). But to what extent would the transportation of iron objects produced by governmental workshops be different from private ones? This is one thorny question that has not been fully addressed. Therefore, this archaeological study focusing on the political core of the Han dynasty, namely the capital area, was the best approach to understanding how small markets and settlements were integrated into the entire national network of commodities.

3.2 Han Government and Financial System

Market exchange and iron commodities were an indispensable part of the imperial finance of the Han state. Meanwhile, governmental involvement was also a defining feature in the structure of the iron commodity economy. In this section, I will first explain the organization of the Han government based on previous intensive works on the Han governmental system (Loewe 2004, 2006) and then identify how the central and local governments managed the administration involved in producing iron objects.

3.2.1 Basic structure of the central and local administration system

One defining feature that distinguishes the political system of the Qin and Han from their predecessors is "bureaucracy", in which the centralized government effectively and efficiently managed local administrative affairs through assigned officials. Preliminary forms of "bureaucracy" existed in the Western Zhou (1046-771 BCE) (Li 2008) or even in the Shang (~1600-1046 BCE) (Keightley 1978) period. But the full blown bureaucratic system—involving the founding of administrative units in distant frontiers and sending officials who were responsible only to the monarch to govern—was completely a new invention during the Warring States period. In the same way, iron production must be contextualized within a bureaucratic system.

After unification, the Qin state already controlled about one-third of the territory of present-day China. A complicated administrative system in the central government must have been created to manage miscellaneous affairs of the entire Empire such as keeping track of maps and census data of all counties. Given its importance in the study of Han history, the governmental system has been quite thoroughly studied and reconstructed in several scholars' works (Bielenstein 1980; Loewe 2004, 2006). Based on these synthetic studies, I summarize the basic structure as follows.

In the central government the administrative affairs were coordinated by the three excellencies (*san gong* 三公), who were second to the Emperor. Below the three excellencies, there were nine superintendents (*jiu qing* 九卿) who took charge of the specific daily administration (Figure 3.1). But their duties were not all relevant to public administration. These superintendents were primarily responsible for activities such as safety in palace, judicial affairs, and state-sponsored rituals; only the superintendent of agriculture (*da sinong* 大司农) took charge of the issues that are relevant to the majority of population in the Empire and to the research here. In general, the superintendent of agriculture and his subordinate officials managed various issues related to the collection of taxes from counties and transporting them to the capital (Table 3.1). The administration of the iron and salt industries were part of the duties of the superintendent of agriculture. Instead of being directly involved in the management of production, the central iron official primarily focused on the coordination of iron production, taxation, and movement of resources between different commanderies through administrative commands.

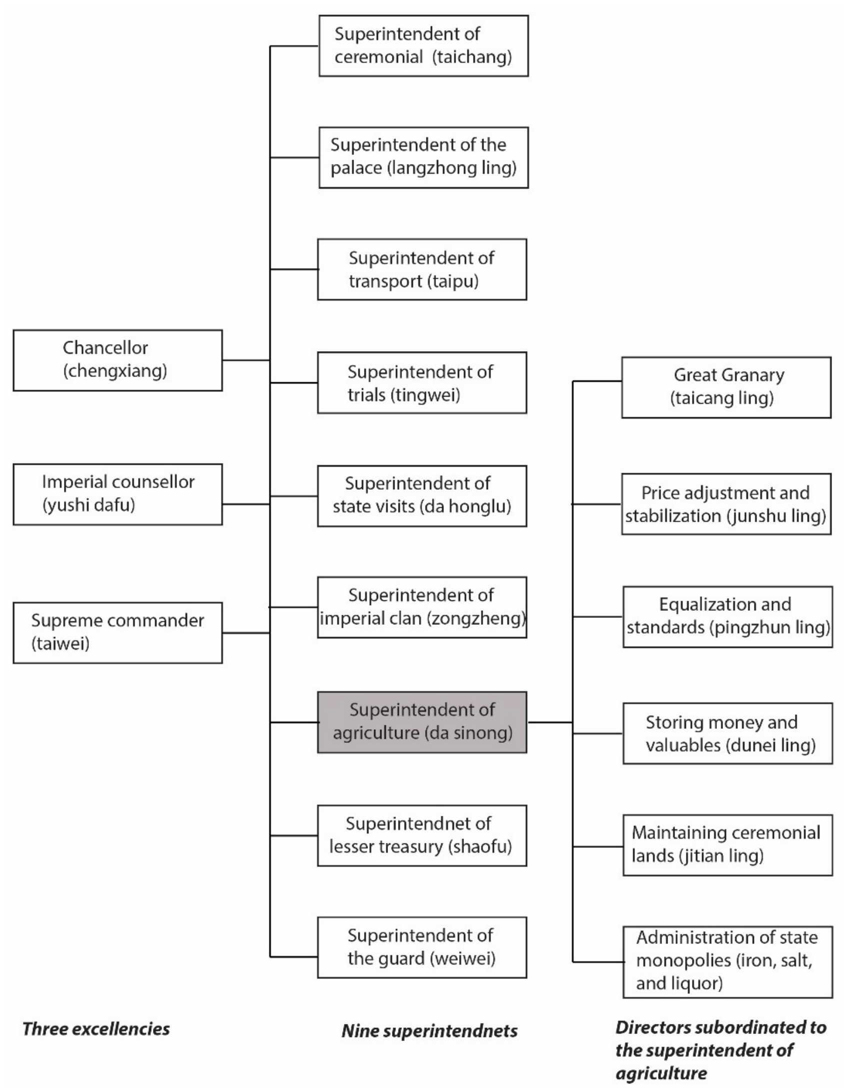

Figure 3.1 General Structure of the Han Central government (According to Loewe 2006)

One thing that is worthwhile to notice is that the reconstruction of the system in Figure 3.1 is according to *Hanshu*, which reflects more the scenario after the series reforms launched by the Emperor Wu, or during the period between the Middle and Late Western Han period. But as many scholars (Wagner 2001:5-6) already pointed out, the position of "iron official" did exist well before the implementation of monopolies. The grandfather of Sima Qian (the author of the

Grand Historian's Records) was appointed by the Qin state as "iron official"[10], probably taking charge of the revenues generated by iron making and the manufacture of iron weaponry. In addition, sealings with "iron office" inscriptions that belonged to the Qi state in the Early Western Han period were found predating the monopoly policies (Chen 1980:107-108), indicating the title and position of iron office did not exist only in the central court. The text *Ernian luling* (二年律令) from Zhangjiashan Tomb no.247, Hubei, which dates to the second year of Empress Lu (187 BCE), even records that officials were responsible to collect taxes as one-fifth of the incomes from those who mined iron and another one-fifth of the incomes if they cast iron objects[11].

Therefore, even before the implementation of monopolies, iron had already became a major part of local and central government finance, and iron offices had already existed to collect taxes from the iron industry[12]. The taxes were collected within the concept and common-sense that all natural resources, including iron ores, were claimed by the Emperor as his own "properties" (Zang 2012). On behalf of the emperor, local offcials collected taxes from the iron industry and then transferred them to the superintendent of the lesser treasure to support the expenses of the Emperor and his royal family. Only during the reign of Emperor Wu did the escalating warfare force the Han government to more intensively move the revenues generated from natural

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[10] *Shiji* 130. 3286.

[11] Zhangjiashan 2001:192, "Jinbulv 金布律".

[12] Some scholars (Chen 1980; Sahara 2002) suggest that, before the implementation of the iron monopoly, the iron industry was controlled by the Han government, local Kings, and private merchants at the same time. But I agree with Kagayama (1984:275, 279) that these iron offices in the Qin and Early Western Han period were only responsible for the production of iron or steel weaponry instead of agricultural implements.

resources to support and cover the massive military expenses on the frontier, which became the foundation for the state control over the entire iron industry.

Table 3.1 The subordinate directors under the superintendent of agriculture and their duties

Subordinate directors	*Duties*
Great Granary	Received the grain; was custodian of a standard set of weights and measures
Price adjustment and stabilization (junshu ling 均输令)	Collected tax that was delivered in other types of kind
Equalization and standardization (pingzhun ling 平准令)	Contrived to stabilize prices of staple commodities
Dunei ling	Storing money and valuables
Jitian ling	Maintained the lands reserved for the annual ceremony in which the emperor handled the plow
Salt, iron, and liquor officials	The administration of the state monopolies.

The local administration system is an important component in the Han government to implement the decrees from the central government, collect revenues, and manage various affairs. The Han empire controlled its territory through a system of commanderies (*jun* 郡) and counties (*xian* 县). Each commandery consisted of certain numbers of subordinated counties and was governed by a commandery governor (*junshou* 郡守). Within the territory of each county, the basic administrative unit is called "*li"* (里), or hamlet. Ten "*li*" then formed a higher rank unit called "*ting*" (亭) (Loewe 2006), which were supposed to take charge of the safety and control of the traffic inside the county. County is the unit above *ting*, and proximately includes ten *ting* in its district. Theoretically, each county in the Han period was supposed to cover an area of 100 x 100 *li* (the length unit; one *li* is equivalent to ~500m). But this framework is only based on an ideal scenario, and the division in reality would be adjusted according to the local geological and topological conditions. In addition, the actual numbers of households and individuals registered under each county, according to the recently found documents from Yinwen 尹湾 and Tianchang 天长 (Hsing 2009; Tiancheng & Tiancheng 2008; Yuan 2011), in general are below 10,000 and equivalent to the scale of about 40,000 to 50,000 individuals.

In terms of the financial system of the Han, one major duty of each commandery was to collect the corresponding amounts of poll taxes (算赋 *suanfu*), which required 63 *qian* (钱) from each individual, according to census data in each county. The resources can be divided into three sections: 1) expends for daily purposes; 2) tributes transported to the central government; 3) support of commendary in peripheries for warfare. Each commendery had to collect 63 *qian* from each individual—which did not include other types of taxes—and transports the goods equivalent to the total amounts of taxes to the government, or known as *junsu* 均输 (Table 3.1). Because of the commercial activities triggered by the state financial system, Watanabe (1989) called into question the high development of commercial activities during the Western Han period. He is skeptical regarding the formation of a uniformed imperial market covering the entire empire. Instead, he suggests underlying the commercial activities was just the coordination of financial resources by the central government, which we will continue to discuss in the section below.

The local governor at the *xian* or county level, called *ling* 令 or *zhang* 正*,* took charge of a wide range of administrative issues related to the financial system. According to prevoius studies on Shuifudi bamboo slips from Hubei, these duties include (Guo 2011; Loewe 2006:47; Ma 1983; Zhou 1999): 1) passing judgments and determining sentencing; 2) collecting land and poll taxes; 3) patrolling and policing for security; 4) governing market activities, including the coinage and weights measurements used in transaction; and 5) managing the livestock and implements that belonged to the government.

The last duty of a *xian ling* is of particular interest here. This is derived from the Statutes on Stables and Parks[13] and Statutes on currencies[14] in Shuifudi bamboo slips. The legal texts indicate that the local Han government managed a quite remarkable number of iron (or bronze) agricultural implements or tools which could be lent to farmers. These objects were branded with specific markers. If these objects were about to corrode, *xian ling* must sell the items in order to collect the cash that these items were worth before every July. The text did not mention who received the scrap iron eventually, but it should be somebody related to the iron foundry which could reuse the old iron. In this sense, the maintaining of iron objects and selling or buying iron goods were an essential part in the administration of these local officials. *Xian ling* might even be the major seller as well as buyer of iron goods (vessels, tools, and perhaps even weapons) in the market. Through the recycling process, the local government also played an important role in facilitating the circulation of iron exchange. In addition, local officials must have the roster to keep track of those who mine iron ores and cast iron objects in order to tax these producers. In other words, the central and local Qin and Early Han governments were heavily involved in the economies and market of iron even within local communities, which might be the foundation for implementing the monopolies.

3.2.2 Iron and salt monopoly

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[13] *Shuifudi*, "Statutes on Stables and Parks", trans. Hulsewe 1985: 28, A9.

[14] *Shuifudi*, "Statutes on Currencies", trans. Hulsewe 1985:54, A48.

After the clarification about the central and local governments, I can move on to explain the issue and debate about the important "salt and iron monopoly" policies that were implemented in 117 BCE and were continued throughout the entire Western Han period. The major source for this policy came from *Hanshu*[15] and *Discourse of Salt and Iron*[16]. From 116 BCE onward to the end of the Western Han Dynasty, the entire salt and iron production system was under the control of the Imperial system. Except for a short period when Emperor Yuan abandoned the monopoly policies, the two industries were directly managed by the government as a means to expand financial revenues.

Although iron, salt, and other resources had already become a major part of the imperial finances even before the implementation of these policies, the involvement was primarily limited to the form of taxing. Before the second year of Yuanshi (117 BCE), private merchants were allowed to smelt iron or even mint bronze coins[17]. But Emperor Wu eventually monopolized these industries by banning all manufacturing that were not conducted by the government. The major trigger of the event was the serious battles and campaigns in the northwest frontiers by Emperor Wu, which almost drained the financial resources of the superintendent of agriculture[18]. The financial dilemma deteriorated even further when merchants took advantage of the opportunity to accumulate goods and manipulated the prices of goods in the market.

To cover the short-fall of imperial revenue, the monopolies of iron and salt were introduced. This idea was first proposed by Dongguo Xianyang 东郭咸阳 and Kong Jin 孔仅, who were also

[15] *Shiji* 30.1425. *Hanshu* 24b. 1161-1162.

[16] Below I will use the abbreviation YTL for *The discourse of salt and iron.*

[17] *YTL*, "Discordant currencies", 4.57, trans. Gale 1967:28.

[18] *YTL*, "Thrust and parry", 10. 132, trans. Gale 1967.64-65.

big iron and salt merchants from Nanyang but eventually became officials taking charge of *da shinong* 大司农. The monopolies focused on several key components: iron, salt, and minting. In addition, the monopolies also include liquor and the setting up of an equable market[19], or *junshu* in Table 1. To implement the monopolies, the government first banned the private production of iron, salt, and coins. In addition, the government established the positions of "iron official" and "salt official" in counties where raw materials for iron mining or salt production were available to take charge of the production of iron goods. For counties without these iron resources, "small iron officials" were set up to take charge of selling or recycling scrap iron. To suppress private minting, Emperor Wu commanded that all coins must be minted by the *shanglin zhongguang* 上林钟官 nearby the capital. The government also tried to standardize the production quality of iron and emphasized disproportionally so-called *daqi* 大器 (probably big iron implements such as ploughshares) and led to the shortage of other assemblages for production.

To put it in a simple way: the new policies attempted to centralize and maximize the revenues from the three major daily necessities: iron, salt, and minting, through prohibiting the participation of private "merchants" in the industries. The role of government in these industries shifted from taxing merchants or producers to managing the entire production processes. This shift also indicated the changing role of the state in the control over resources. As scholarly works have long recognized (Li 1957), the revenues of the Han government[20] included two parts: those for the government or imperial expenses and those for the emperor's family, other royal members, and Kings or marquises. The imperial expenditure was paid by the royal revenues,

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[19] *YTL,* "The basic argument", 1.1., trans. Gale 1967: 2.

[20] But after the reign of Emperor Gongwu, the first emperor of Eastern Han, the royal expenses were also paid by the imperial treasure. In other words, the royal and state financial system became the same one.

except for large projects like the construction of mausoleums that was supported by the imperial treasures. As most natural resources were monopolized for the private exploitation by the Son of Heaven and the lands or natural resources (e.g., forest, ores, wood, salt) that were owned by the royal families allowed soldiers, convict labors, and slaves to work. Part of the products thus became the tribute to the royal families for sacrificial and royal expenditure. But assigning the superintendent of agriculture to manage the monopolies indicates the shift of the ownership and its role in state finance. Since the government now was responsible for operating and coordinating the whole production process for the entire Empire, the revenues were now changed to support warfare in the frontier rather than supporting the royal families or their sacrificial activities.

For this reason, the nature of iron and salt are different from other craft industries which were only for royal and elite consumption (Li 1957:180). The monopoly policy means the iron industry shifted from the *shaoshu* 少府 to *dalong* 大农 system, or from the royal to the state financial system to provide relief for financial stresses. Although this shift changed the nature of the iron industry, it might not have entirely changed the landscape of the iron industry. Just like Dongguo Xianyang and Kong Jin were originally iron merchants or foundry owners, the government probably incorporated the private iron industries and assigned those who were willing to cooperate with the government as iron officials as agents to manage the operation of iron industries while other non-corporative iron foundries were eventually banned.

Meanwhile, the change of the nature of the iron industry does not necessarily mean an increase of the degree of specialization or efficiency in production. Nor did the iron monopoly mean, archaeologically, a sudden appearance of new iron foundries in each country. More than likely, the local government just took over the management or control of iron foundries that already existed, or just changed the originally "private" merchants or entrepreneur into officials as local agents of the government. It is reasonable to assume that the implementation of the new political policies would not have completely changed the landscape of the iron industry, as officials were selected directly from original iron and salt merchants. Some iron foundries might have been abandoned, but many of them would have become iron officials eventually or changed to large officially-owned workshops.

Furthermore, the production of iron tools might have needed to take the local environment into consideration. But as stated later in the *Discourse on salt and iron*, "when the magistrates establish monopolies and standardize, then iron implements lose their suitability, and the farming population loses their convenient use."[21] In some cases, officials produced poor quality iron tools in order to meet the production quota and even forced farmers to buy these products. As in the monopolized system, the products produced by centralized government-owned foundries might only respond to the administrative order to produce instead of responding to the market demands, the large-scale state-sponsored iron industry came at the price of quality and adaptability to the local environment.

Having all these issues in mind, we should raise our concerns in applying anthropological concepts to generalize the nature and organization of iron industries before or after the monopoly policies were introduced. During the Han period, iron might have been produced by merchants, but their supply and demand were not entirely controlled by market forces. Since the local *xian* government might have been the largest buyers of iron products, the transaction of iron products might still be under the control of the government in order to guarantee the amounts of products

[21] *YTL*, "Hindrance to farming", 5.68, trans. Gale 1967: 83.

obtained by the government. In this sense, the iron industry might not be entirely independent and owned by a private entrepreneur (Satō 1962). While the iron industry was controlled by the hand of individual specialists, which would easily fall within the category of independent specialization, the production is still under the control of the government as these workers needed to register and pay taxes according to their final production. It is also important to note that even before the monopoly policies, cast iron foundries in various sizes might have already been established in the various counties; otherwise, it is hard to understand how *ling* officials would be able to sell broken or corroded items for recycling even in Yunmeng, a frontier for the contemporary Qin Empire.

To summarize the introduction to the Han political system, it seems more than clear that iron—even though some scholars would argue it belonged to the domain of private industry—was significantly controlled or managed by the Western Han government in many direct or indirect ways even before the monopoly policy. This pattern indicates governmental control in the distribution of goods and workshop operation needed to be taken fully into consideration.

But for the information that can help explain the iron industry like the assemblages of final products and how workers were recruited, textual records only provide a brief sketch. Thus, below I will summarize the development of iron technology during the Western Han period to provide the background information about the iron economies. Furthermore, discoveries of major iron foundries will be introduced below to understand the structure or organization of an iron foundry in the Han period

3.3 Development of Iron Technology and Organization of the Iron Industry in the Han Period

The main purpose of this section is to introduce the development of iron industry based on an archaeological perspective. Since textual records only provide a description of the governmental control over the iron industry, this section attempts to lay down the foundation through a review of relevant archaeological records to explain how iron technology was employed in the production and how iron production was organized.

3.3.1 Development of iron technology pre-dating the Han period

Because of the rapid development and ever-increasing social demands, during the Han period unprecedented large iron foundries were found in areas where resources are particularly rich. All these new and large iron foundries are considered to belong to "official workshops" or large iron offices in the literature. Because of the remarkable scale and complexity of these workshop sites, these iron works have attracted lots of attentions in the past. Especially, the techniques employed and their structure have been very well analyzed and summarized in the literature (Li 1994, 1995, 2000; Wagner 2001). Before I start with particular focus on the structure of iron industry in the Guanzhong Basin, I will briefly introduce these discoveries with particular focus on their organization and characteristics that are relevant to the theoretical schemes discussed in Chapter 2.

But before unfolding the discussion about the development of the iron industry in the Han period, it is necessary to lay out the trajectory of iron technology in China during the late Bronze Age in order to understand the background of this unique technological development. As voluminous metallurgical studies demonstrate, the transition to cast iron in China was set into motion at the end of the Springs and Autumns period (770–454 BCE) or earlier (e.g., Hua 1999:303; Han and Chen 2013) and became widespread during the Warring States period.

Furthermore, experiments with iron smelting started relatively early in East Asia. In the Central Plains, although the earliest worked iron was meteoric iron, which was made into blades during the middle of the Shang period, around the fourteenth century BCE (Han and Chen 2013; also see references in Han 1998), research has shown that bloomery smelting was introduced to the Hexi corridor—the major pathway between eastern and central Asia—around the same time (Chen et al. 2012). By the end of the Western Zhou, the use of bloomery iron was finally established when it became a type of prestige good (Chen et al. 2009; Henan and Sanmenxia 1999).

Cast iron innovation appears to have been set into motion in multiple areas shortly after their invention about the sixth or fifth century BCE, and during the Warring States period, the quantity and variety of iron products already witnessed a rapid increase. The variation was not only in types but also in materials used for iron items. During the Warring States period, materials had already included decarburized iron, white iron, gray iron, malleable iron, malleable iron with nodular graphite, and solid-state decarburized steel (Han and Duan 2009). Except for the technique of refined pig iron, the major aspects of the technical foundation had been laid down well before the Han period. The wide spread of the iron technology in the Han period just employed these well-founded techniques on a much larger scale.

In short, before the founding of the Han Empire, almost every major state had already finished the technological transition from bronze to cast iron and established relatively large scale cast iron production. The system that focuses on the production of agricultural tools on a large scale also was well established before the founding of the Han Empire. Although the specific forms or shapes of agricultural tools would be different according to the locale environment, the production of iron tools, especially agricultural tools, was the defining hallmark of the craft industry throughout the entire Warring States period in all these states. Alongside this transformation, the local network for the distribution of iron objects might have become more developed. As a result, even before the Qin unification, some large cities such as Linzi in Shandong had already been considered as “international” craft centers, and the dominance and advantage in craft industry of these centers continued to last during the Qin and Han period (Bai and Shimizu 2007).

Nonetheless, it is not surprising to see that a discrepancy might have existed regarding the iron technology between these major states. Although cast iron and associated fabrication techniques were the major development and trend of this time, local traditions had already emerged. For example, metallurgical study shows that certain iron swords were made of bloomery iron, indicating the tradition in the weapon industry of the Zhao state might be distinctive from other states (Beijing 1975). The tradition of bloomery iron in northeast China also continued to last even until the later historical period. Also, in the case of the Qin state, a large scale iron production site has not been reported yet. Large amounts of molds for casting iron agricultural tools were not reported during the archaeological works in either Xianyang or Yong 雍. Perhaps the Qin state was not so much advanced in iron technology in comparison to other three-Jin states. The unification of the Qin and Han Empires contributed more to integrating independent market networks with distinctive techniques and creating a more cross-regional network and transportation system.

3.3.2 Organization of the iron industry in the Han period

During the Han period, the most important technical improvement is the appearance of refining iron technique. Building upon the preceding developments, the iron industry reached one of its peaks during the Han period. The excavation of iron foundries in present-day Henan and Shandong provinces provide a vivid image of Han iron production about its widespread and mature fabrication techniques. During the 1960-80's, large excavations were conducted in Wafengzhuang 瓦房庄 (Henan 1991), Guxin 古荥 (Zhang 2009; Zhongguo 1978), and Tieshengguo 铁生沟 (Henan 1962; Zhao, et al. 1985). Some small-scale iron foundries were also reported on the edge of Nanyang Basin (Li 1995), Jiudian 酒店 (Henan & Xiping 1998; Qin 2010), and Hebi 鹤壁 (Hebi 1994). Among them, the excavation of Wafengzhuang is the largest excavation of ironworks during the Han period so far. More than 4,000 sq meters have been unearthed. Therefore, the development of iron foundries in present-day Henan province was studied the most extensively and provide the best analogical information to understand the structure and operation of iron officials and iron foundries. More recently, a series of iron works in Shandong have been investigated. The recent archaeological works in Dongpinglin 东平陵 and Linzi also provide the best example to illustrate the operation of the iron industry in the eastern edge of the Empire. These excavations not only provide fresh data to supplement our knowledge about the iron industry in this region but also significantly broaden the understanding of the organization and generate the material for analyses.

According to survey and excavation, most of these identified iron foundries were large-scale ironworks[22]. The three well-excavated iron foundries (Tieshengguo, Guxing, and Wafangzhuang) all covered more than 20,000 m^2. Among them, Guxing was the largest single

[22] Besides these major large iron foundries, some local and small foundries were found in recent year such as the one at Zhujiaji (Zhangjiajie 2003). The two loci only covered very small area (less than 2000 sq. m) and included one or two furnaces. Perhaps due to the local tradition, the brief report suggested local workers used a "crucible" to re-melt cast iron material, which might have been transported to the site from another place, and used "cast iron molds" to cast iron objects. In addition, wells were found at these loci and significant amount of daily-used and serving vessels were found.

iron foundry that has been found so far covering over 120,000 m^2. At this site, one of the two[23] largest iron smelting furnaces, which is oval-shaped with a long axis of 4 meters and a volume of 50 m^3 was found. The two largest cupola furnaces that have been found so far were all located in Henan province. In terms of environmental setting, Tieshenguo is located in the foothill of Niuer Mountains. Jiudian and Wangchenggan are also adjacent to mountain foothills. Thus, the blooming of the iron industry, especially in the Henan province, was attributed to the rich resources as well as the advancement and improvement of technology, which eventually fueled the spread and application of iron technology to increase[24] the production of iron through the enlargement of the furnace.

In spite of the fact that the detailed organization of these ironworks is still underexplored, archaeological data already explicitly show that these examples usually include multiple functions. For instance, the Wafangzhuang foundry (Western Han stratum) included both iron cupola furnaces, iron smithing furnaces, mold-firing kilns, and probably puddling/refining iron furnaces. These are adjacent to a ceramic workshop to the north and a coinage mint to the south. The entire iron foundry belonged to one part of a mulit-crafting center. On the rim of the Nanyang Basin, at least 10 relatively small smelting sites have been confirmed. Even though the date of these sites are based upon survey collection and still debatable, scholars suggest that these sites might support exploitation of raw iron resources, probably in the form of ingots, to the production center inside the town or city (Li 1995).

[23] The other example has been found at the Wangchenggang 望城岗 site in Lushan (Chen, et al. 2011).

[24] One issue has not been fully studied in scholarship is the efficiency of using furnace on such a large scale. The instrument also required new improvements with regard to air-blasting (air circulation) to make sure the homogeneity of air circulation inside the furnace. Otherwise, iron would be cooled down and block the flowing of liquid iron.

At Tieshengguo, features that were found include 8 (smelting) furnaces, 1 smithing furnace, 1 decarburize furnace, 1 puddling furnace, and 11 mold firing kilns. The site can also be subdivided into difference components including smelting, melting, decarburizing, and hammering. In addition, the foundry conducted not only cast iron smelting but also bloomer iron or even puddling steel production. At the nearby Guxing foundry, because of the small excavation area, it is unclear if other types of iron were produced at the site. But it seems very likely that large iron foundries produced more than one type of iron, and conducted more than one type of production procedures in order to maximize production efficiency (e.g., decarburizing and smithing). Besides setting up large ironworks, survey and excavation in the Xiping and Wugang areas show that in some iron production area, contemporary clusters of relatively small iron smelting iron centers might have been the major focus of iron production. Preliminary archaeological work also shows that these small ironworks might have subdivided and conducted different parts of the iron production (Qin 2010).

Recently, excavations at the Linzi walled town also exposed a foundry or foundry complex which consisted of at least 4 sections focusing on different products or different procedures (Yang, et al. 2013). The four loci are all located at Kanjiazhai 阚家寨. According to the survey and analyses of manufacturing remains, bronze and cast iron production overlapped at least one location. The site also included smelting, and, very likely, ore sorting, grinding, and crushing processes. In the foundry, a row of smithing hearths was identified. The study of slag remains collected on survey (Du, et al. 2011) also indicates that the iron foundry conducted the refining processes. In other words, Linzi represents the type of holistic iron foundry that conducted almost every step of production procedure.

In terms of the product assemblage, these iron foundries primarily produced agricultural tools through casting, based on casting molds that were found. For instance, in almost all excavated iron foundries, the major types of ceramic molds were used for casting agricultural tools, including hoes, plows, spades, and sickles, which is definitely related to the popularity of oxen-pulling and agricultural techniques. During the Eastern Han period (25-220 CE), cast iron molds, which could have been resembled and reused many times, were put into production and significantly improved production efficiency. At Wafangzhuang, other categories include large iron basin with a radius of over 1.5 meters, iron vessels, iron weights, hammers, and chariot fittings, which cover more or less the same assemblage of products at Guxing. Furthermore, since new materials (i.e., puddling iron) were quite widely employed in production, and smithing furnaces were found at these sites, types of products might have even included weapons (e.g., swords and halberds) and tools that were formed by hammering or welding different types of iron materials together.

Most importantly, inscriptions show that most of these iron foundries were related to the iron officials and provided the link to the governmental system mentioned in texts. The two cases in Guxing and Tieshengguo (called Heyi 河一 and Hesan 河三 respectively) might be under the control of the same iron office in Henan commandery but specialized in slightly different production processes (Li 2000). For some cases where the scale of production was too large or extensive, one iron official might oversee multiple foundries, which might have focused on different procedures. According to inscriptions on casting molds, Guxing might have been the first foundry controlled by the iron official in the Henan commandery, while Tieshengguo might have been the third foundry (the second foundry is still mysteriously absent in archaeological records). Wafengzhuang was considered to be related to the iron office of the Nanyang commendary as inscirptions “Yanyi” indicates there must be other ironworks under the same iron office. To allow the iron industry to arrive at its full-fledged development, the Empire must have developed a complicated system to administer these foundries and coordinated the production at foundries not only in Guandong but also in the capital area.

Archaeological evidence, in fact, significantly supplement textual records and enhance our understanding of these iron foundries. First, textual records usually briefly touch upon the labors employed in iron production, but archaeological cases clarify that these foundries often were structured like a “supplementary network”. A significant portion of the final products in the assemblages were agricultural tools, but in large workshops like the case of Wafangzhuang, vessels and chariot fittings were also co-crafted by the same group of workers. The transportation of final products, raw material, or even production tools, might not have been unusual since some big ironworks evidently manufactured much more than others in terms of the amounts and the types of products. Moreover, the functions of these iron foundries depended on the natural environment and the proximity to resources. For instance, Wafengzhuang used scrap iron as the major sources of raw materials, while Guxing and Tieshengguo could obtain iron ores and conduct iron smelting.

Second, because of the exchange of resources, these iron foundries did somehow connect to each other or even were controlled by the same iron official. For instance, inscriptions show that Guxing and Tieshengguo both belonged to the iron offices of the Henan commandery. Under the same iron official, there might have been some forms of labor division between different nearby ironworks. Archaeological evidence also shows clear subdivisions in some ironworks in each step of procedures production (smelting, casting, refining, and smithing). The recent discoveries in Shandong even show that the iron office in Dongpingling imported molds manufactured by the iron office of the Taishan 泰山 commandery (Shandong et al. 2011). This discovery indicates that, in some cases, an iron office could coordinate with other offices to share or circulate raw materials as well as final products of casting molds.

It is unquestionable that these cases were major production centers for the entire region. Archaeological data also sketch out the profile of the iron industry in general. What is missing, however, is a piece of information about the production and distribution of iron in the local center. Or to put it in another this way, how iron production was managed or organized in the gap area between these large centers still remains poorly understood. In addition, previous studies focus more on the reconstruction of techniques and the assemblages of final products. Various types of manufacturing waste were not reported in a detailed manner, not to mention the waste from daily activities. It is almost impossible to employ the frameworks discussed in the beginning of this dissertation. More importantly, the data that we have are concentrated in Henan province. For this reason, the case study in this dissertation provides additional information about the production system near the Chang'an capital

Summary

In this chapter, I explained the meaning of commodity in previous scholarly work, and addressed to what extent the debate about commodity is different from the definition and understanding in other disciplines. Through the review of literature, I tried to demonstrate that commodities in the domain of historical research often refer to the long-distance exchange of goods, the appearance of markets, and the variety of goods that were sold and purchasable through market exchange. In other words, the issue related to the production process and even "alienability" were rarely involved in the discussion. Accordingly, I will explain later how the case study of the iron foundry at Taicheng enhances our understanding of the iron industry and the definition of "commodities" in the context of Han history. Referring to the discussion in Chapter 2 about the integration of various small markets, the form and structure and the market and the exchange of commodities are always the major debated issues in this regard. For this reason, it is particularly helpful to focus on a specific region—e.g., Guanzhong in this study—to illustrate detailed aspects about the iron industry at the local level.

As mentioned earlier, since the discussion has to take into consideration the characteristics of the Han economic activities–the intensive involvement of the Han government in various market affairs—I will first briefly introduce the structure, organization, and authority of the central and local government to provide the background information in the next chapter to facilitate the discussion about iron—including its whole "social life"—in the Han financial and economic system. This explanation also further clarifies the factors of governmental involvement that we need to take into consideration during the discussion of the commodity or market economy.

Iron commodities were part of state finance from the very beginning of the Han Empire. The government did not employ a completely laissez-faire policy in iron production. Rather, before the implementation of monopoly policy, the Han government got involved in the iron industry through taxing. The change of governmental role is more relevant to the degree of state control, as the Han government since then directly set up iron officials to manage and coordinate every step or procedure in iron production. Thus, the monopoly policies might not completely change the organization of the iron industry. The way iron was manufactured, I believe, did not change very significantly. Iron foundries that were allowed to survive might employ similar techniques with similar standardization skills in the production.

Yet, published archaeological evidence that we have is not substantial enough to address the debate. A more productive way is to focus on the structure of the industry and exchange network as a whole to understand how the production was integrated into the exchange network. Although the large iron foundry demonstrates some forms of labor division, a serious issue is still left unaddressed. Iron was a commodity that has to rely on craft specialization, but the intensity of specialization has not been fully understood. Also, the resources and techniques of these cases usually were under-investigated in terms of the incorporation of analyses of production remains as well as the exchange of resources and final products.

Archaeological study in this case study, therefore, can contribute to pushing forward the research regarding this set of issues. By drawing on multiple lines of evidence regarding the iron industry during the Han period, the discussion in this chapter provides a relatively comprehensive image about technique, management, organization, and even the political significance of iron by the central and local government. Evidently, the discussion about commodities in the anthropological framework can provide a starting point for us to re-conceptualize the issue of commodities in the context of Han economies. Also, those iron foundries that have been extensively excavated and studied are all large in scale and probably correspond to the "big iron office" in literature, but for small iron foundries, the archaeological work is sparse, and the publication of information was limited. There is an important missing part of the iron production system during the Han period. For this reason, the case study of Taicheng serves as an important piece of information that complements our understanding of iron production and Han commodity economies in various aspects. In particular, the case study can provide a new and concrete example to not only help improve our understanding of the theoretical challenges in anthropology but also help to clarify the imperial economic system that has not been precisely understood before.

CHAPTER 4

LANDSCAPE OF THE CAPTIAL AREA AND INTRODUCTION TO THE TAICHENG SITE

Introduction

The Guanzhong Basin was the cradle of the rise of the Qin Dynasty. The Western Han dynasty—the successor of the Qin—similarly constructed their rulership based on the strategic advantage of the Basin. In *Shiji* Chapter 99, Liu Jing 娄敬 proposed his suggestion to Emperor Gao regarding the location of the new dynasty. In his opinion, Guanzhong, or the old Qin land, possessed strategic advantages over Luoyang. His argument, in fact, fully captures certain essential strategies of Guanzhong. He argues,

"*……the area of Qin, surrounded by mountains and girdled by the Yellow River……..enjoys the advantages of its vast and fertile fields possesses a veritable storehouse created by nature. If Your Majesty will enter the Pass and make your capital there, then, although there should be an uprising east of the mountains, you can still keep complete control of the old land of Qin. Now when you fight with a man, you have to grip his throat and strike him in the back before you can be sure of your victory.*"[25]

Since the foundation of the Han Empire was based on different strategies between Guanzhong and Guandong[26], namely the areas to the East of Hangu 函谷 pass that were

[25] *Shiji* 99.2716, trans. Watson 1993: 237.

[26] According to Xing (2011 [1983]), this term also refers to areas on different scales. One refers to the area covering all other six states during the Warring States period, while the other one, which was formed during the Han period, refers specifically to the eastern part of the empire except the northern frontiers and the area to the south of the Hui River.

originally controlled by the other six states except the Qin state. The military advantage[27] imposed over the other portions of the Empire (e.g., Xin 2008), and economic strategies to maintain the control by the core formed the foundation of Han rulership. Having this issue in mind, this chapter introduces two relevant aspects in order to delineate the geological and historical settings of the Taicheng site. First, from a macro-perspective, this Chapter will explain and introduce the landscape of the entire Guanzhong Basin, including palaeo-environment, the pathway of transportation, the layout and structure of the Chang'an capital, and the archaeological discovery of craft production in county-level settlements. I try to shed light on the material foundation and political administrative system of Guanzhong that allowed it to "grip the throat" and "strike the back" of the eastern territory.

Within this background and concepts of the capital area, I will then introduce background information about the site of my case study, Taicheng in the second part. Besides the history of the site and nearby areas, the second part will cover the discovery and excavation of the foundry as well as features identified. Since the site was primarily used during the Western Han period and the stratigraphy of the site is relatively simple, the chronology and date of the site are based on a comparison with datable materials and ceramic chronology. In addition, this section will discuss other background information that is essential for the analyses that I will conduct in following chapters.

4.1 Geological Setting, Transportation System, and Population in the Han Period of the Guanzhong Basin

[27] A similar opinion can be also seen in *Shiji* 55.2044: "the three sides of [the Guanzhong] were circumscribed by a natural boundary. There is only one side to control over eastern Kings. If they were subordinated, food from all over the world could be transported to the capital through the road pathway and water channels of the Yellow River and Wei River. If there was rebellion, armies and military supplies could be moved eastward along the Rivers."

The capital area of the Western Han is often referred to as “Guanzhong” in texts. After the war between Han led by Liu Bang and Western Chu led by Xiang Yu, the Han dynasty first made Liyang the capital, and soon moved to Chang’an in 206 BCE due to the natural environment that facilitated the development of agriculture and the transportation system. These major advantages alongside other natural resources significantly contribute to a large population and the region’s unique political role. During the Qin and Warring States period, the topography also allowed the Qin state to take advantage of this strategic geology to dominate and conquer other territorial states during the unification wars. In the Western Han period, Guanzhong continued to be a strategic military center to control the eastern part of the Empire and the northwestern frontier. Furthermore, as I will explain below, Guanzhong was constructed as the center of state-sponsored rituals and ceremonies. All these factors have to be taken into consideration concerning commodity exchange in this region.

4.1.1 Environment and agriculture

Here I start with the introduction and definition of Guanzhong and clarification of geological terms. In texts, the exact area covered by this term changes depending on different contexts. Broadly speaking, Guanzhong means all the areas of the west of the Hangu pass, including the Shaanbei plateau, eastern Gansu and the upper reach of the Wei River (also called Longdong 陇东), and the Chengdu Basin. These areas are more or less equivalent to home territory of the original Qin state before the unification. Guanzhong can also refer more specifically to the Wei River Valley circumscribed by the four passes in four directions (Hangu pass in the East, Wu 武 pass in the South, Pu 蒲 pass in the North, and Dasan 大散 pass in the West) (Wang 2007), or equivalent to the area that is “within the Passes from the Qian River and

Yong eastward to the Yellow River and Hua mountain."[28] To be more specific, this smaller-scale of Guanzhong refers to the area bounded by the Qian and Yong Rivers in the West in present-day Fengxiang and by the Yellow River and Hua Mountains in the East. Geologically, this river basin appears to be a narrow strip bounded by the plateau, mountains, and the Yellow River, and extends from West to East about 300 km. In the discussion below and other chapters, I adopt the narrow definition to define Guanzhong to the Guanzhong Basin or the lower Wei River valley.

The topography of the Guanzhong Basin also made it well-known for "rich soil and watered lands for a thousand li"[29] and well-developed agriculture. The entire Guanzhong Basin was transected by the Wei River, the largest tributary of the Yellow River, originating from present-day Gansu. The Wei River includes two major tributaries: Jin 泾 and Lou 洛 River. In the Guanzhong Basin, most arable lands are distributed along the river valleys or between these rivers systems. Since the Wei River and its tributary rivers started from the loess plateau, they brought rich loess sediment from the North and contributed to the formation of a rich alluvial plain and flat landform in the region. Also, the basin in present-day southern and western Xi'an area was extensively intersected by many small tributary systems (Wang 2004). The moving of rivers cut the river bank and created numerous terraces and small plateaus, which are the defining geological characters of the Guanzhong Basin. Consequently, these geographical factors combined together to contribute to the high yielding and productivity of agricultural lands in the basin.

Studies on palaeoclimate show that, during the Qin and Early Western Han period, the Guanzhong experienced a relatively warm optimal period—which is about the present-day

[28] *Shiji* 129.3261, trans. Swann 1974[1950]: 437.

[29] e.g., *Shiji* 129.3261, trans. Swann 1974[1950]: 437.

annual temperature at about 6-13℃. But the environment and temperature shifted to a dry and cold period after the Emperor Wu's reign (Ge 2011; Ge, et al. 2006; Zhu, et al. 1998; but see Chen 2002). During the Early Western Han period, the Guanzhong Basin was intensively covered by vegetation and bamboo forest[30]. The favorable environment further accelerated the rapid agricultural boom in the Guanzhong Basin and providing the material foundation for the formation of early empires.

To facilitate the production of agriculture, large scale canal projects were conducted during the Qin and Han periods, especially during the reign of the Wu Emperor. These engineering projects intensively transformed the entire landscape of the Guanzhong Basin. These canals include Zhengguo 郑国 canal, Bai 白 canal, Liufu 六辅 canal, Longshuo 龙首 canal, and Chengguo 成国 canal[31]. In general, these canals can be categorized into three groups: Jin River system canals (Zhengguo, Bai, and Liufu), Luo River system canal (Longshou), and Wei River system canal (Chengguo). These canals are primarily concentrated in the eastern part of the basin where the landscape consists of large plains divided by many tributaries (Figure 4.1). The construction of these canals allowed the Han (and Qin as well) governments to connect different portions of the same river system or join two River tributaries together through state-sponsored projects. All together, the canals and irrigation network in the basin fueled and stimulated the development of agriculture by joining different river systems to cultivate areas in between. Eventually, the fertile plain and developed agriculture made Guanzhong fully becoming the stable food production center and provided an essential economic foundation for the Qin and Han Empire. Meanwhile, agricultural tools were all made of iron (or steel), and this material

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[30] *Shiji* 129.3272, trans. Swann 1974[1950]: 451.

[31] *Hanshu* 29.1678~1679, 1681, 1684~1685.

even became an important resources in which “the life and death of farmers” lie during the Han period[32]. The advanced and intensified agricultural industry must rely on a massive scale of production or transportation of iron production to meet the social demands of agricultural implements.

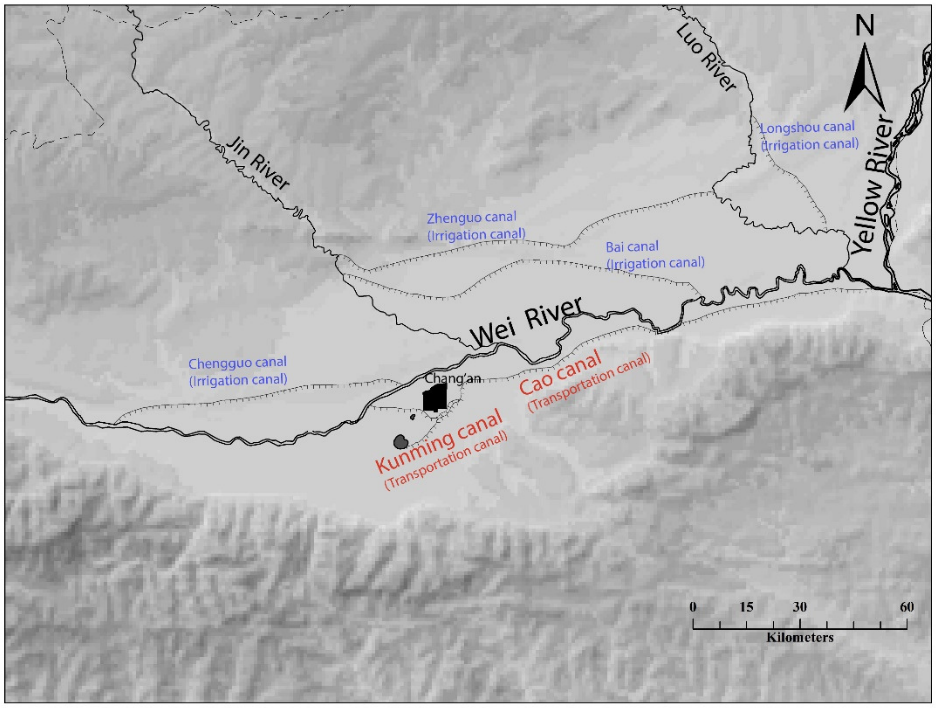

Figure 4.1 Canal systems in the Guanzhong Basin
(Redrawn from Will:1998, Map 9.3)

4.1.2 Pathways and channels for resources transportation

In comparison with the farming industry and agricultural production, Guanzhong is not well-known for the richness and variation of natural resources. For the minerals that we are concerned with here—iron, modern geological survey (Shaanxisheng 1993; Zhongguo 1996a:142-143) shows no large iron ore deposits inside the basin, and most iron ores are only small or medium scale deposits (Figure 4.5). Other natural minerals like copper are also rare in the basin and even

[32] *YTL,* “Hindrance to farming”, 5.68, trans Gale 1967: 32.

on the edges in the mountains. Iron and copper ores would only be found at the southern edge and eastern edge of the basin, but these ores are not extremely rich to support the demands for production. To support to production and consumption in the entire basin, raw mineral resources had to be transported to the heartland of the empire from smelting sites, probably in the form of ingots.

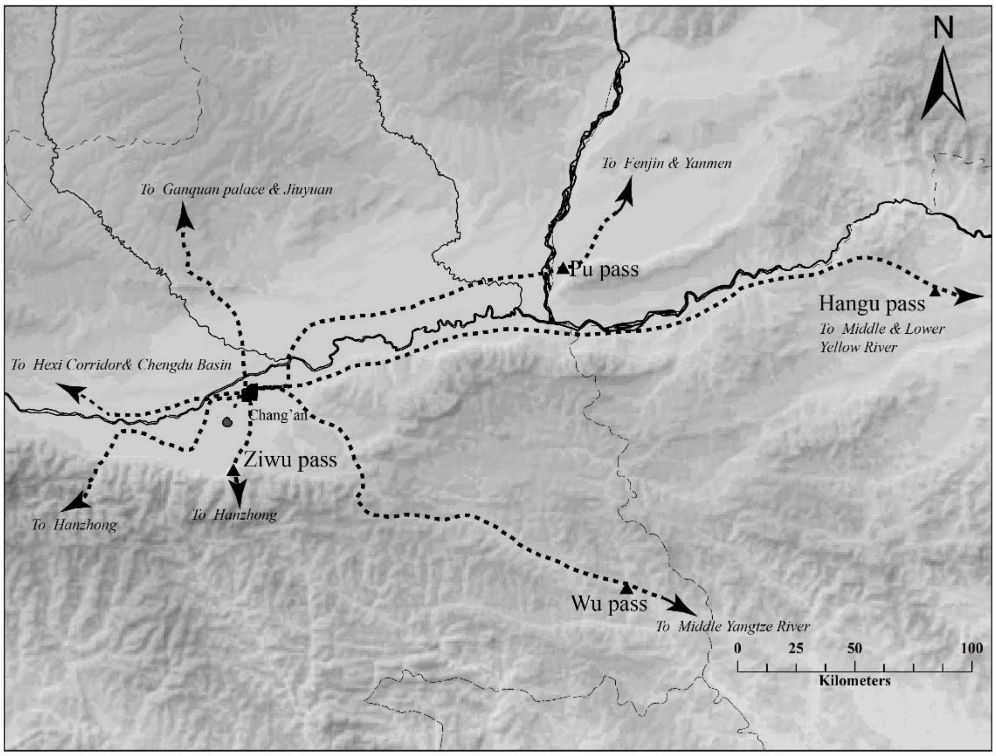

Figure 4.2 Pathways of the Guanzhong Basin
(Redrawn from Xin 1988, Figure 1.)

On the other hand, Chang'an was conceptualized as one of the imperial metropolises[33] (Li 1957:200) given its importance in the commodity exchange and trading markets. *Shiji* Chapter 129 mentions:

[33] *Hanshu* 24b.1280.

"…….In accord with (Ch'in [*Qin*] preference to rule from within the Passes) the Han made its capital at Ch'ang-an [*Chang'an*]. From various imperial tombs in the four directions [to the capital, on road like] spokes of a [wheel into] the hub, came [the people] from these different directions, gathering together [in the capital]. The [amount of] land was small, and the population was crowded. Therefore, the people became more and more frivolous and crafty, and engaged in secondary (occupations, that is, trading and crafts)."[34]

The prosperous commercial activities in Chang'an were attributed to its unique geographical locations in which the urban city lies in the center of the Guanzhong basin. Geographically, the basin situates at the join-point of several major pathways that connect to different parts of the Empire. The East-West direction pathways, namely Weibei 渭北 pathway and Hangu pathway, were the two major land roads that communicated to the eastern part of the empire and the Longxi region, or known as the northwestern frontier. The south-north direction pathways were the Wuguan 武关 pathway and Ziwu 子午 pathway (Figure 4.2). The former extends to the Han River valleys and the Nanyang Basin, while the latter could communicate to Hanzhong or even the Chengdu Basin (Xin 1988, 1989a). Therefore, Chang'an can be viewed as the transportation center of the entire Guanzhong Basin or even the entire Empire. The strategic location of the capital also allowed the Empire to impose control and to monitor the movement of people through the pathways and transportation networks (Xin 2010).

The essential role in economic exchange of Chang'an was also attributed to the river networks. Geologically, the widest part of the Wei River surface lies in the Chang'an city. The entire city and its outskirts were surrounded by the Wei River and its seven tributaries (Ba 灞,

[34] *Shiji* 129.3261, trans. Swann 1974[1950]: 437.

Chan 浐, Fong 澧, Hao 滈, Lao 洛, Jin 泾, Lao 涝, and Yu 潏) in a concentric network (Shi 1996). This intricate river network system provides an ideal natural production as well as transportation channels for the capital.

One major type of goods transported through the river network was staple foods (e.g., millet) from the eastern periphery to the center of the Empire. Despite the fact that the agricultural development was advanced in Guanzhong, the yield still could not fully support the original population and a large amount of migrants from the Guandong area, not to mention the staple foods transported to the frontier for warfare. Moving resources, especially staple foods and raw materials, from the eastern part of the empire to the capital became an essential mean to support an ever-growing empire. But the Wei River was not naturally suitable to serve as a large-scale transportation channel as the volume of water was not stable and large enough throughout the year for shipping staple foods and materials from the lower reaches of the Wei River to the capital. In addition, since the lower Wei River channel is not straight at all, the turning of the channel significantly increased the time and costs of moving resources through shipping. In order to facilitate the transportation of such tremendous amounts of stable goods from the eastern part of the Empire, Cao 漕 canal was constructed to direct the Wei tribute to the west of Xi'an to merge or join to the Yellow River[35]. This canal also directly connected to the imperial warehouse (*taicang* 太仓) in southeast of the capital walled-town (Xin 1989b) for storing staple foods from the eastern part of the Empire and then transporting them to the northwest frontier. With the help

[35] *Shiji* 29.1409-1410.

of engineered canal systems, Emperors of the Western Han dynasty were able to move and transport a tremendous amount of millet (粟) to Guanzhong from the eastern territory[36].

In addition to canals, storage facilities were also an important part of the imperial transportation system. Besides the imperial warehouse mentioned above, the empire also set up several large-scale storage facilities along the Wei River. In Huaxian 华县, the capital warehouse (*jishicang* 京师仓) (Shaanxi 1990) was set up just adjacent to the location where the Wei River merged with the Yellow River. This storage was used for collecting agricultural products produced from the eastern part of the basin and shipped back to the capital. In addition, food from the eastern part of the empire could be stored here temporarily if the water level of the Wei river was too low for shipping. To the west of Chang'an, the Xiliu warehouse (*xiliucang* 细柳仓)[37] was set up for collected agricultural yielding in the area covered by the Chengguo canal (Xin 2010). Furthermore, a recent discovery in Baoji indicates that the canal network could extend further to the West. At the site called Sunjianantou 孙家南头, which is adjacent to the Qian River, a docking site and associated storage facilities were discovered (Shaanxi et al. 2005). Clearly, these large storage house were built at the two ends of the basin aiming to facilitate the transportation of stable goods consumed by the large population in the capital area and supported the warfare in the northwest frontier or the consumption at imperial palaces.

For this reason, textual and archaeological evidence indeed support the understanding that resources (e.g., food) were moved or transported on a massive scale from the East to West along

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[36] During the reign of Emperor Wu, the amount of staple goods transportation involved 6 million *dan* or *shi* 石, see *Hanshu* 24a. 1411. In later period during the reign of Emperor Chao, the amount was slightly lower but still involved about 4 million *dan*, see *Shiji* 30. 1441. 4.

[37] *Sanfu Huangtu*, "仓 *cang*", 6.347.

the Wei River, Cao canal, and land pathways. Unfortunately, the state sponsorship or control of transportation has been poorly understood in previous literature. The details of the transported items especially have not been sufficiently investigated. But since the transportation system was able to move staple foods on such a massive scale, the same system should not have had any difficulty moving craft products for commoners (e.g., iron tools) from the eastern territory to the core. This developed transportation system might also have played a key role in the rise of the cluster of satellite urban centers nearby the Chang'an capital and made Chang'an the transportation hub for food and other types of commodities.

4.1.3 Population

The importance and significance of the Guanzhong Basin was also attributed to the high density of population in the region. In the Han period, textual records[38] provide the irreplaceable census data about this issue. The labor forces (including males and females) that could be called for constructing the city wall of Chang'an reached 146,000 from the region within the six hundred li (equivalent to almost the entire Basin). By adding up all kinds of residents together, including servants, merchants, officials, elites, and royal families, the entire regional population might even have reached the level of 3.9 million in the Early Western Han period (Shan 2008).

During the Early and Middle Western Han period, the Empire had forced a large portion of the population in the eastern territory to relocate and resettle in the capital, which further contributed to population growth in the region. For instance, during the construction of the Maoling mausoleum, Zhu Fuyan 主父偃—one of the major advisors to Emperor Wu—proposed to send those who were influential gentry, usurped others' properties, or created social turmoil

[38] The most important data about the demography in the Western Han period came from *Hanshu* 28. This chapter is based on the census conducted in 2 CE.

from the eastern territory to Maoling in order to strengthen the capital area and eliminated those who were crafty by one policy[39]. The Maoling mausoleum town ended up hosting up to 270,000 people in 2 CE, and this density is almost equivalent to a modern urban center (e.g., Tianjin) during the 1980's (Ge 1990). Having hosted the migrated population, the entire population registered under Jinzhao 京兆 commandery, which included a total 12 counties, reached the level of 682,468 from 195,720 households[40] close to the end of the Western Han period, and Chang'an county alone already had 80,800 registered households representing 246,200 people[41].

The rapid increase of population was primarily attributed to the forceful movement of migrants to satellite towns or mausoleum towns. As Zhu Fuyan's suggestion that I cited before clearly explained, the Han government viewed relocating population—most of them were aggressive or rich chiefs, feudal lords, and strong or large clans—to the mausoleum towns as a major means to eliminate factors that would potentially trigger rebellions in the eastern territory. The Han Emperors eventually constructed a total of 9 mausoleum towns—7 of them are overlooking the northern bank of the Wei River, while 2 of them are situated on the southern suburbs of Chang'an (Figure 4.4)—to monitor the influential figures that they tried to suppress. Therefore, a great portion of the population recorded in the census include a wide range of categories, including descendants of influential families, officials, and individuals associated with Kings or Marquises, Confucian scholars, members of the army, medical practitioners, and, most importantly, servants and eunuchs (Huang and Xu 2012). In this sense, the Chang'an

[39] *Shiji* 112. 2961.

[40] *Hanshu* 28a.1543.

[41] Whether this census information realistically reflect the population size of the capital is still debatable (Wang 2007). This number would probably include those living in village or district 乡 outside the capital. According to texts, there are 160 *li* (里, here refers to the village or district) inside the capital; but how they were distributed was completely unclear.

capital and nearby mausoleum towns were constructed as a full-functioning metropolitan clueter (Ge 1990) that was based on developed markets to transport all items, including both necessities and exotic goods, to all residents.

As scholars (Ge, 1996; Wang 2004) focusing on the Han demography have also pointed out, the population density in the Guanzhong Basin, especially in the habitable flat land, was about 1000 people per square km close to the end of the Western Han Empire, which was the highest in the entire Empire. Since significant numbers of population in the capital area (especially in urban centers) could not engage in any agricultural or craft production activities, the construction of transportation canal and other irrigation systems appeared to be necessary means to make intensive agricultural production possible and acquire enough resources to support daily consumption on a tremendous scale. Since iron was not a resource only for agricultural implements but also all sorts of tools in daily life, research on the production and transportation of iron resources in the capital area, in fact, significantly improves our knowledge about the economic infrastructure of the Han Empire that was underexplored before.

To summarize the description of the landscape of the capital area, there are three particular aspects essential to contextualize the iron industry in the region. First, the demand for iron for manufacturing agricultural implements in Guanzhong might be extremely high as this region was an important area for agricultural production in the Han period. Second, the capital area was conceptualized as the hub of the transportation network of the entire Empire. In addition, as iron resources are limited in the Guanzhong Basin or even nearby regions, iron goods might be among many other items transported to the capital through the state-sponsored network. Third, the demands of iron came not only from the production of agricultural implements. Since the density of population here was almost the highest in the entire Empire, and a good portion of residents were servants and elites, the demand for the wide range of daily-use goods that were made of iron such as cauldrons, knives, and daggers should also be extremely huge. How the social demands were met and satisfied by the supply system of iron again was one of the key issues in the study of the Han economic system.

4.2 Qin-Han Archaeological Discoveries in the Guanzhong Basin

This section provides another perspective on the political and economic landscape of the capital through archaeological evidence. Textual prospective about the Guanzhong landscape clearly supports and highlights a developed transportation network linking and coordinating all settlements together with the supply system (e.g., for iron) from the eastern imperial territory through consumption and exchange. Section 4.2 supplements this understanding through introducing archaeological discoveries related to craft production and consumption of the Qin and Han periods. This line of information can also provide a broader context to understand the social and economic function of the case study below. In addition, archaeological information can provide a more detailed dimension about the network of urban centers to contextualize the discussion about the production and transportation of iron commodities that I will introduce and reconstruct in chapters below.

4.2.1 Chang'an city and Shanglin 上林 *Park*

The capital walled-town Chang'an covered 36 sq km, not including other detached palaces, a royal hunting Park, and state-sacrificial sites associated with Chang'an. The construction of the capital city took place primarily during the second year of Emperor Hui. The enclosing wall only took 1 month to construct by drawing 240,000 labors from an area "600 *li* in the radius" from Chang'an[42], but the entire project—including palaces and complexes—took a total of 6 years.

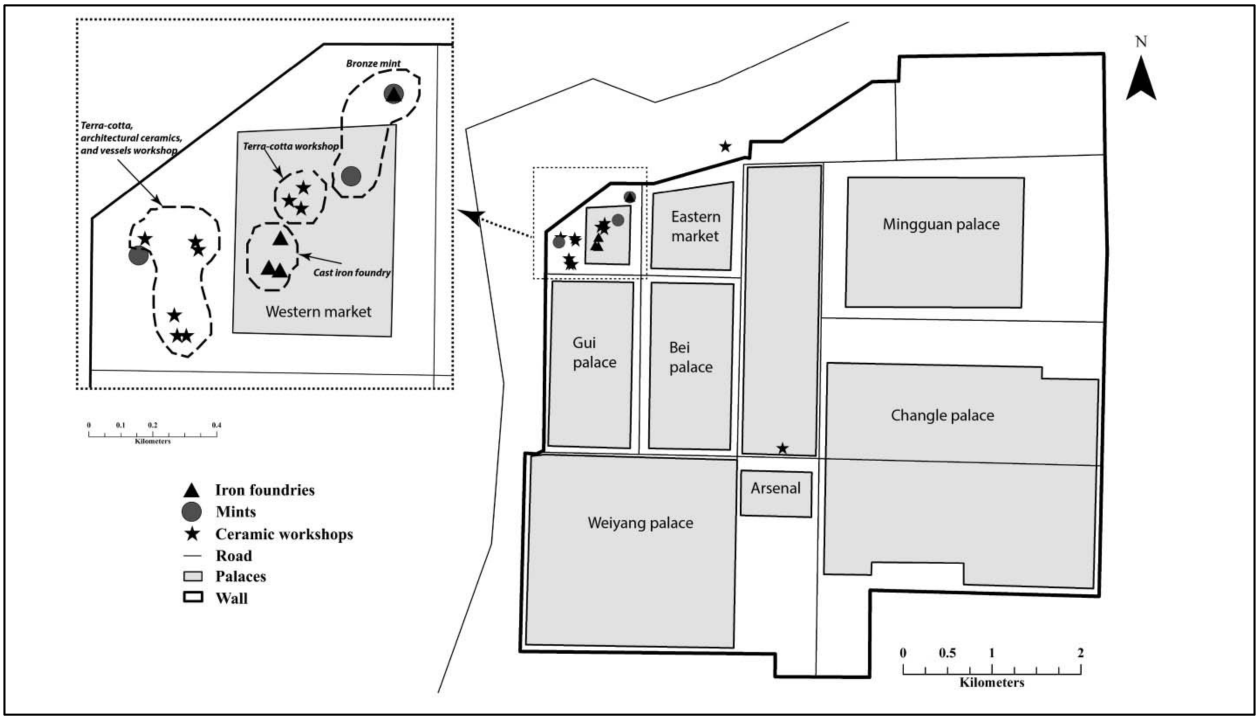

Figure 4.3 Chang'an palace and locations of production remains
(Redrawn from Bai 2011: Figure 2)

Previous archaeological works focused particularly on palaces (Liu 1995; Liu and Li 2006), the arsenal site (wuku 武库) (Zhongguo 2005), road systems, and the structure of gateway (Zhongguo 2009). In accordance with archaeological surveys, two-thirds of the site was fully occupied by various temples, royal storage facilities, and royal palaces (Liu 2000; Pirazzoli-t'Serstevens 2010). Each palace in fact was a group of royal complexes and was enclosed by a wall. The entire capital wall was therefore divided into 11 sections by the road system (Figure 4.3). But only the Weiyang palace and Gui palace complexes have been extensively excavated and fully published (Zhongguo & Riben 2007; Zhongguo 1996b). Each complex included

[42] *Hanshu* 2.89.

several groups of architecture and served different royal members. In general, the major purpose of the capital was to serve the royal and imperial families and the central administrative system. Each group of complexes was specifically assigned to serve different members. For instance, the Weiyang 未央 palace was primarily occupied by the Emperors, while the Gui 桂 palace was for the queens and other concubines. Commoners might have resided only in a small section at the northwestern corner of the walled town, but the majority of them—both farmers and commoners who were not conducting agricultural production—might have lived outside the walled town (Wang 2007). Commoner cemeteries or tombs were intensively and densely distributed in the eastern and southern suburbs of the capital walled town. The distribution patterns of these cemeteries will be introduced in detail in Chapter 8. According to the site report of the tombs in Longshouyuan (Han, et al. 1999), residential remains were also identified during the salvage excavation of the cemeteries. It is no doubt that middle or low class commoners were widely distributed widely outside the capital city.

Craft production remains and production sites have been found concentrated in the northwestern corner of the capital city (Zhongguo 1995, 1997). Most of these workshops produced goods that served royal purposes—including terra-cotta funerary figurines, ceramic building material for temples, and iron chariot fittings, and coins (Bai 2011). Kilns for firing architectural ceramics—i.e., tiles and bricks—were also sporadically found inside the capital city (Figure 4.3). It is believed that the northwestern corner was also location of one of the nine markets associated with Chang'an (Liu 1987). But in comparison with the scale of craft production remains found in capital cities predating the Western Han, the scale of these workshops were curiously small. In addition, the majority of final products were not associated with commoners' consumption. Take the ceramic workshops for example. Although some ceramic workshops (or kilns) might have belonged to individuals instead of being controlled by the government (no.23-27 kilns), the majority of these workshops produced tiles, and terra-cotta for high-status elite tombs. For the iron industry, the two excavations only identified remains associated with the production of chariot-fittings; no manufacturing waste associated with agricultural implements or daily-use tools has been hitherto found inside the city. In short, the manufacture of iron products and weaponry that were excavated from the capital and adjacent cemeteries seems to have occurred elsewhere, and Taicheng is one probable source.

The scale of production inside the Chang'an city was also by no means comparable to other capital walled-towns predating the Western Han. For instance, in Xianyang, the capital of the Qin dynasty, a large-scale ceramic workshop was found at present-day Maojiatan 毛家滩, and primarily produced daily-use serving vessels by ceramic workers dwelling in different *li* 里 (ward). To the north of the Xianyang, a high density of kilns for firing ceramic agricultural components were found at a site called Niejiaguo 聂家沟. Iron foundries seem to be small in comparison with other Warring States examples such as the Zhonghang 中行 foundry in the Han capital city in present-day Xinzheng (also see Chapter 6). Furthermore, there is still no evidence indicating the production of bone tools, but animal bones were still required on a large scale as name tag or tablets.

While the capital seems to downplay the role of craft industry inside the city, the government set up large-scale workshops and assigned officials to manage coin minting after the implementation of the monopoly[43] within the area of Shanglin Park. These workshops and other related large scale architectures have been systematically investigated through pedestrian and

[43] *Hanshu* 24b.1169, trans. Swann 1974[1950]: 293-294.

magnetic surveys (Zhongguo & Xi'an 2006, 2007c; Zhongguo & Xi'an 2007a; Zhongguo & Xi'an 2007b). As a result, archaeological works has generated a much clear image about the organization of the entire royal park and the structure of the bronze mint inside. The Shanglin Park is in the Western suburbs of Chang'an. It was a royal hunting Park and also hosted the production of coinage. Palace foundations and associated water drainage system were identified. The entire Park stretches over 300 *li (*里)[44], which is equal to 124 km. The site includes various small Park sections for raising royal hunting livestock and palaces[45]. Thus, the entire Park covers a large area that involves present-day Xianyang, Huxian, Zhouzhi, and Liantian, and the outskirts of Chang'an was surrounded by the Shanglin Garen and became an essential part of state economy.

Extensive manufacturing remains related to bronze minting have been found through magnetic survey, indicating the entire workshop was well-planned and might have been divided into several sections. During survey, remarkable amounts of molds for casting bronze coins were found. In addition, the survey team also identified certain remains associated with production other than bronzes (e.g., iron crucibles). No experimental works have focused on these materials, but is not surprising that the Shanglin coin mint foundry would have been a multi-craft workshop. Therefore, the Shanglin Park, or the outskirts of Chang'an, might be considered as imperial lands privileged only for the Emperor and the royal family. After the monopoly policies were in place, the Zhongguan was assigned as the imperial mint for minting coins[46] supporting the entire State.

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[44] This *li* is used here as the unit of measurement, not the administrative unit.

[45] e.g., *Shiji* 58. 2084.

[46] Outside the Chang'an, Chengcheng 澄城 (Cui 1982) is the only coin mint that is identified and even relatively well-published. This site is also a small-scale foundry site and is located at present-day Potou village in Chengcheng, about 70 km east of Xi'an. Its major function is a coinage minting foundry. Molds include ceramic, bronze and stone molds three types. It is highly possible that the site was responsible for mold production. A well-

This area is not just for royal hunting and sacrificial rituals but also served as an official craft production center.

4.2.2 Mausoleums, mausoleum towns, and detached palaces

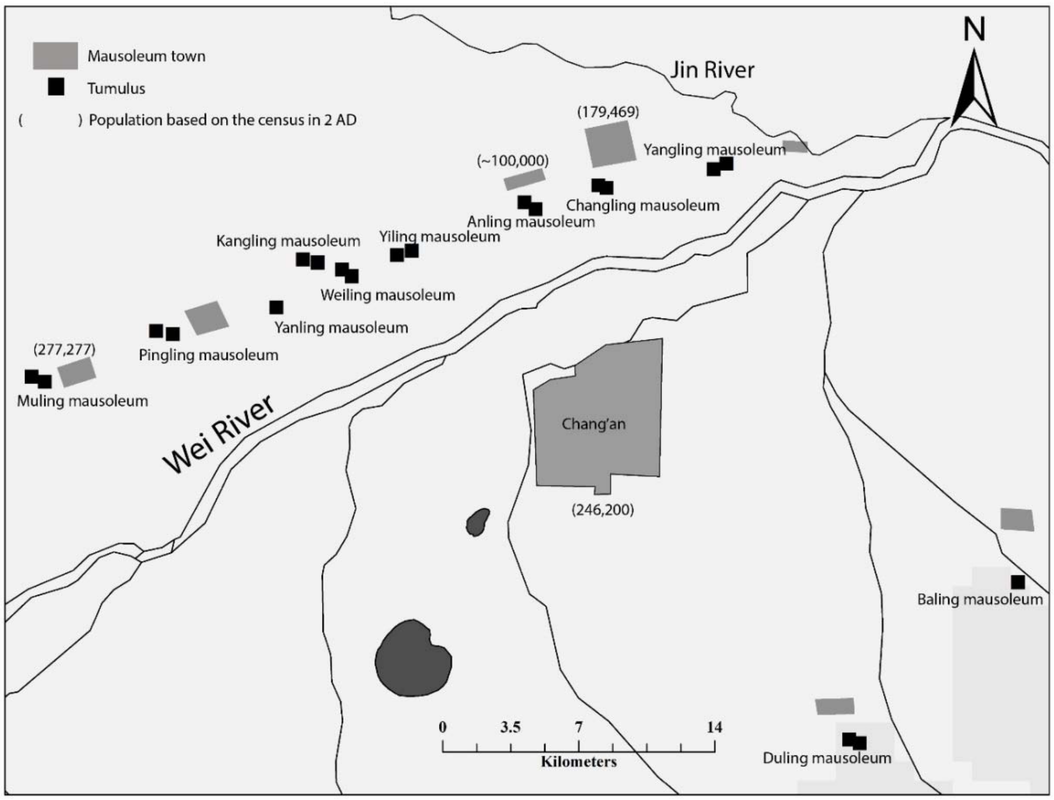


Figure 4.4 Distribution of mausoleum towns
(Redrawn from Xianyang 2007: Figure 1, p.3)

During the Western Han period, the mausoleum towns and Chang'an comprised a satellite city network. These special urban centers indeed played a crucial role in the Han economic system during the Han period. A total of 9 mausoleums have been found on the northern bank of the Wei River while two of them were distributed to the South of the Chang'an city. Among them, Maoling hosted the largest population with 277,277 people within the mausoleum town

preserved kiln was also excavated during the excavation. The site may belong to the town of cheng or congquan county, and indicating the minting production during the Western Han period would have taken place outside the Shanglin garden.

area[47], which was the largest residential town in the entire Guanzhong Basin and even more densely occupied than Chang'an in 2 CE.

In accordance with previous investigations and reconnaissances in the past decades (Jiao and Ma 2011; Ma 2011; Shaanxi & Xianyang 2012, 2013; for the most intensive summary of previous works, see Xianyang 2000; Xianyang 2007; Zhongguo 1996c), each mausoleum include a number of sections: the tumuli and tombs of Emperors and Empresses—which are circumscribed by enclosing walls, outside storage pits, accompany burials, and mausoleum town. Substantial amounts of food (Yang, et al. 2009), animal sacrifices, and exotic goods (Shaanxi 2008b), were buried in the outside storage pits (*wai cangguo* 外藏椁) (Jiao 2006, 2013) associated with the tumuli for what kinds of purposes. Attention in previous work (e.g., see summaries in Xianyang 2000) has been given predominately to the mapping of the tumulus and the layout of associated features. In terms of mausoleum town, it is reported that the Maoling mausoleum town was the largest one among the nine mausoleum towns discovered and covers over 5.5 sq. km, which is the second largest residential settlement in the entire Guanzhong area.

As mentioned earlier, the system of mausoleum towns was set up to resettle influential local families or lineages from the Guandong area. These migrations also hired and controlled certain numbers of bound servants. These new settlements appear to focus exclusively on the consumption instead of craft production. This system was abandoned during the last four Emperors. As a result, no mausoleum town associated with the last four mausoleums: Yiling, Weiling, Kangling, and Yanling (Figure 4.4) have been identified when the strategy of relocating the wealthy families from Guandong to mausoleums created more social discontent and criticism

[47] *Hanshu* 28a. 1547.

than stability[48]. According to survey results, most of these mausoleum towns mentioned above were circumscribed by enclosing walls. Road systems and architectural complexes were identified through augering. Kilns or ceramic production facilities were only sporadically found inside the area of mausoleum towns (Xianyang 2000). Nor were remains associated with other types of manufacture remains (e.g., bronze or iron) frequently reported in the voluminous preliminary reports. At this stage, it is still difficult to use archaeological evidence to prove if large scale craft production did not take place in these satellite centers.

One inescapable issue related to these mausoleums is related to their layout. Nine of them are distributed in the North bank of the Wei River, while two of them were to the South of Chang'an. Debates primarily surround the symbolic or cosmo-political meaning of such design and layout (Shen 2001; Yang 2009; and see references therein). According to Yang Zhefeng's recent study (2009), the first mausoleum is situated on the long "axis" that extended from the capital to the northeast. Also, most of these mausoleums appeared to be distributed along another conceptualized long axis parallel to the Wei River and orientated about 20 degree to Northwest in order to form another axis perpendicular to the long axis mentioned above. The construction of mausoleum projects along this long axis might embody the idea of elongating the rulership of the Han royal family for many generations. If so, these mausoleums should be viewed as an engineering project to demonstrate and visualize the rulership of the Han Empire.

These mausoleum towns with such high density of population might have served as "magnetic" center to draw resources to the great metropolitan area, but the consumption was not limited within the cluster of satellite urban centers. Besides the high-density population centers,

48 *Hanshu* 27a.1341.

the landscape of Guanzhong was also intensively occupied by detached palaces and sacrificial temples distributed throughout the entire capital area. One important example is the separated palace in Qianyang 汧阳 Shangjialing 尚家岭 (Shaanxi et.al 2010), has been systematically surveyed recently. Excavators suggest that the complex might have been one of the imperial villas or detached palaces (*ligong* 离宫) in the Guanzhong Basin (Tian 2010) mentioned in texts[49]. Results show that these sites include not only clusters architectural remains but also other complexes like freezer-storage rooms and even small workshops managing instrument, like *ding* vessels, used for sacrificial activities.

Another major site complex with organized archaeological works is associated with the Ganquan 甘泉 palace. This site complex is associated with the Yunling mausoleum. The entire site occupies more than 1.75 sq. km and belonged to one major detached palace that Emperors visited periodically. During the Han period, over 50,000 households were forces to migrate and resettle at Ganquan. Multiple rammed-earth foundations have been found within the site-complex area (Yao 2003). Within the county area, a ceramic production site associated with the Yunling mausoleum was also identified. The significance of Ganquan is relevant to two factors. Ganquan was the location of *taishi* 泰畤 (Tai altar) for conducting state-sponsored rituals[50]. In addition, Ganquan is on the straight road and important in controlling the communication between the Chang'an capital and the northern frontiers such as Jiuyuan 九原[51]. In other words, the network that was supported and fueled by imperial consumption and state sponsorship was

[49] *Hanshu* 51. 3267.

[50] For examples, see *Hanshu* 6.205.

[51] For the discussion about the construction of the straight road and implications in the political rulership, see (Sanft 2014)

not circumscribed within the area of the capital or the Shanlin Park but extending throughout the entire Guanzhong Basin, which further substantiates my argument that there should be a corresponding network to transport resources and support the massive demands of various kinds of goods.

4.2.3 Urban centers and other workshop sites in the sanfu 三辅 region

The vast area outside the Chang'an capital in the Guanzhong Basin, also called *sanfu* in texts, was subdivide into significant numbers[52] of administrative towns or counties of different sizes. Through the national survey projects in the past, considerable numbers of Qin-Han residential sites—some of them were even walled towns—have been identified (Guojia 1998). In juxtapose with textual records on the commanderies and counties, some of them, especially those with enclosing walls, could be assigned to the capital of these commanderies and counties. Unfortunately, so far almost none of them have been substantially investigated. For those sites with enclosing walls, survey data sometimes offer more detailed data, such as the size and scale of the enclosing walls as well as a basic description of remains identified on the surface. But for the sites without identifiable remains of enclosing walls on the ground surface, the site estimation is solely based on the area where artifacts and features were found.

[52] During the Qin period, there are 41 counties in the entire Guanzhong. The Han government basically adopted this administrative system and added 9 more mausoleum towns. The three commandaries consist of 57 counties mentioned in *Hanshu*.

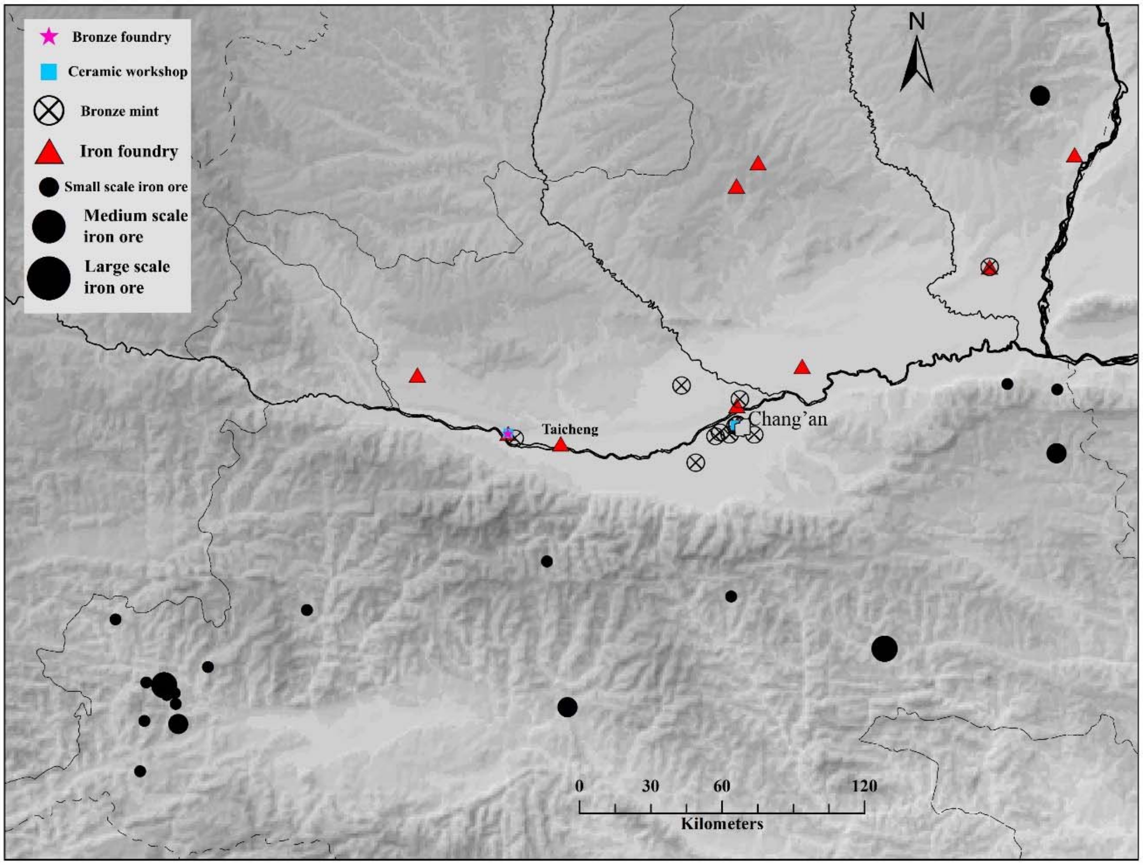


Figure 4.5 Map of production remains and iron ores within the Guanzhong
(Data from Bai 2005: Appendix 1; Shaanxisheng 1993:152-153)

Without any systematic investigation and study on post-depositional process, it is better to view the estimated size of site derived through pedestrian survey as reference data about scale instead of the actual reflection of sizes of these settlements. According to a previous study in the size of the wall-towns (Chen 2007), the majority of county town is smaller than 0.5 sq. km. In these regional centers, iron or other types of craft manufacturing waste was sporadically found. But since none of these sites were systematical investigated, below I will introduce the discoveries in three locations as examples to present how craft production (Figure 4.5) would have been organized in local centers.

<u>Liyang 栎阳 walled town</u>

In the Han period, Liyang was one of the most important county town in the Guanzhong Basin, and provides the best example of this area to illustrate the structure of a Han county during the Western Han period. Even though the site is just a county-town, but its walled-size is about 4.5 sq. km, which is the second largest county town in the entire Guanzhong Basin, following the Maoling mausoleum town. The important role of Liyang is due to several factors. Liyang once served as the capital of the Qin state before Xianyang. Liyang even shortly served as the imperial capital before moving to Chang'an. During the Han period, Liyang was the also the town of the Wanlian mausoleum (Emperor Gao's father). Its significant role also reflected in in Zhanjiashan bamboo slips, which mentions Liyang[53] was one of the higher-ranked counties, or known as *qiandan zhi xian* 千石之县, in which the officers *xianling* received relatively higher salaries (1000 *dan* or *shi*).

According to archaeological works (Liu and Li 1985; Shaanxi 1966), the entire settlement was enclosed by ramped earth, and iron slag were found at three loci. Among them, locus V dates to the Han period, and loci VIII dates roughly to the Qin and Han period. The nature of locus V IS determined through iron slags and red-burnt soil. But its area is very small (200 m x 150m), and the deposition of stratigraphy is just about 1.5 meters. Each locus of the three workshops is small in scales. Molds for casting chariot-fittings were found. In particular, at least 10 pieces of molds for casting plows[54] were found, which would be alike the remains found at Taicheng. Also, slag was found accompanying ceramic production tools like peddles and unfinished products. According to ceramic inscriptions, Liyang was also a ceramic production

[53] *Zhangjiashan* 2001: 193, "秩律 *zhilu*".

[54] Unfortunately, no images have been published about this type of remains.

center. Ceramics with Li 栎 inscriptions dating to the Qin or even Han period were found at Chengcheng and Weinan. Evidently, Liyang was a multi-craft production center:

<u>Yaoshang 尧上 ceramic workshop</u>

Cemeteries, kilns, storage facilities, and other features that were associated with production sometimes were sporadically found in other residential sites or counties towns. In general, archaeological or even textual records about the production outside the capital were very tenuous. Recently, the excavation of the Yaoshang 尧上 ceramic workshop (Shaanxi 2011), which is associated with the town of Mei 眉 county, perhaps is the most important one and provide the best direct evidence to extrapolate the economic foundation of these local administrative centers.

The augering survey suggests the site-complex, including the ceramic workshops, may extend over more than 70,000 sq. meters. Only 2,000 sq. meters have been excavated, and part of the workshop, like the ceramic firing area, have not been identified yet, indicating medium-scale workshops did exist in the county town. Close to 200 pits were found yielding substantial amounts of daily-used vessels and architectural tiles, ceramic-making tools like paddles and molds for making figures and tiles. Other features include 8 wells, 4 moats, 6 ceramic-coffin tombs, and 2 adult burials. The function of moats was unclear as they crossed the entire site. It is noteworthy that inscriptions indicate workers might have originated from other settlements such as Taiting, Baling 霸陵. Laborers of this workshop were unquestionably associated with other settlements including Tai that we are going to discuss later.

According to ceramic typology, this site preliminarily dates from the Middle Western Han to the Eastern Han period. Survey suggests there are clusters of rammed-earth remains to the north and southwest of the excavation area, which may be related to the enclosing wall of the town. In addition, within the radius of 3~4 km centered upon the workshop, there are considerable numbers of Qin-Han burials, but at the center of this circle the numbers of tombs were not high. As burials usually were on the outskirts of the town, the workshop may be located at the center of Mei county. Furthermore, Yaoshang is not the only location showing connections with Taicheng. From the nearby Baijia site, local archaeologists even collected eight pieces of sherds with inscriptions of "taiting" (斄亭) (Shaanxi 1996). Although the sherds date to the Qin period, these sherds are related to the ceramic production center that was controlled by the Tai county 30 km away.

Given the fact that the practice of cross-crafting between the iron and ceramic industries was popular during the Warring States and Han periods, it is not surprising to identify remains associated with cast iron production in the assemblage of manufacturing waste. In the remains that are still under analysis, I identified at four pieces of molds for casting iron ploughs. Judging from the outlook, both the shape of molds and the shape of final products are highly similar to the molds that were found at Taicheng. In the assemblage of manufacturing waste, a considerable number of molds for casting bronze belt hook and probably chariot-fitting were identified. Judging from the number, the amounts of iron or bronze manufacturing waste appears to be very limited in comparison with the waste associated with ceramic production. Workers in the ceramic workshop might have just engaged in part-time and occasional production of metal goods.

<u>Nangucheng 南古城 iron foundry</u>

The Nangucheng site in Fengxiang is the most western location where iron manufacturing remains were identified in the Guanzhong Basin. The iron production is located in the southeastern corner of a small-size Han walled-town, probably the county town of Yong. The site was excavated during the 1950's (Qin 1980; Shaanxi 1962). In the preliminary works, both ceramic and stone molds for casting tools were found. In addition, in one of the ceramic vessels, an inscription was found at the base of a bronze *ding* vessel, suggesting the *ting* market governing institute may have existed nearby the site. In previous excavation, molds for casting agricultural tools including ploughs and hoes were identified. The shape of the molds and the product assemblages were very similar to the materials at Taicheng. My survey in 2011[55] identified piles of tile production, indicating a tile production workshop or facility existed nearby the town of Yong. Nearby the iron foundries, there should be a workshop associated with tiles or architectural remains production. Although the premise date is still ambiguous, it is certain there were two types of workshops located within the area of the town. Slag and molds for casting ploughs were identified through my survey at two loci, but these discoveries are sporadic and no remarkable waste depositions were identified. In accordance with the distribution of remains, however, the scale of iron production seems to be very small.

Summary

For the large or major county towns, archaeological works in the past decades might not be enough to fully depict the organization of craft industry in the entire Guanzhong area. Besides the cases mentioned above and the Taicheng case that I will introduce, remains associated with ceramic production kilns, either for vessels or molds, and coinage casting molds were

[55] There was no other location related to iron production except Nangucheng has been found. As there is supposed to have been a *tieguan* (iron office) in Yong, this location might have been the foundry associated with the state-controlled foundry.

sporadically found in the basin. Unfortunately, their date is always ambiguous. Nor is the relationship with the nearby settlements very clear. But through the introduction to these works at county-level settlements, it is still possible to gain a glimpse of the organization of iron and ceramic industries outside the capital area regarding various aspects.

First of all, the discovery of multi-craft production workshops (e.g., a ceramic workshop adjacent to an iron foundry) seems to be common in large or major county towns such as Liyang and Yong. Even in smaller or less important counties such as Meixian and Taicheng, manufacturing waste of ceramic, bronze, or iron industries can be sporadically found. Given the large population that dwelled in the Guanzhong Basin, it should not be surprising to identify that each county-level settlement conducted some sorts of craft production to manufacture daily-use products for residents.

Second, in terms of the scale, iron production in these local centers (Nangucheng, Taicheng, and Yaoshang) did not appear to be organized on a massive scale. For instance, at Nangucheng iron manufacturing waste was sporadically found by the survey conducted by me and my colleagues[56]. The scale of all these cases was even particularly small in comparison with the iron foundries in the eastern part of the Empire such as Nanyang and Guxing as I mentioned before. The production of ceramics, however, may have been somewhat different from the scenario of the iron industry. The Yaoshang is so far the largest ceramic workshop that has been identified in the entire region. Its area might be more than 7 hectares[57], which is even larger than the ceramic workshop—which is about 3 hectares (Shaanxi et.al 2013)—at Yongchang controlled by the Qin

[56] In 2013, I and my colleagues in Shaanxi also conducted a survey on the iron production sites in Hancheng and Tongcun reported before. At these sites remains were also sporadically identified.

[57] This figure is just a rough estimation based on the result of augering. The core area of the ceramic workshop might be much smaller than this.

state. Perhaps even before the implementation of the monopoly policy, there might have been some degree of variation in the control and management of different craft industries.

Third, evidence shows that craft industries discovered within the great Chang'an area were mostly not relevant to daily-use products for commoners. The coinage mint in Shanglin as well as ironworks and ceramic foundries in the northwest corner of Chang'an were all managed by the state and manufactured either prestige goods or resources that were tightly subject to state control. Except for the coinage mint in Shanglin, the scales of craft production were also very small even in compariosn with other discoveries related to craft industry in the basin. Instead of a good production center, the archaeological discovery reinforces the statement before that the capital as well as its satellite cities focused heavily on the function of exchange and trade. Moreover, the entire capital area was also occupied by lots of separated palaces and temples for royal resorting and sacrificial activities. The Han political core seemed to intensively focus on agricultural production, commodities transportation, and various forms of state-controlled rituals. In contrast, except minting, craft production was not the key component in the structure of the capital region from either textual or archaeological evidence. The study of the iron industry in a local setting must take the political landscape and the regional (or even interregional) transportation network of iron sources.

4.3 Discovery and Excavation of the Taicheng Foundry and Its Associated Site-complex

The clarification of the key concepts and spatial structure of Guanzhong is significant in contextualizing the case study of Taicheng foundry and its associated site-complex in two senses. First, the site itself is small and similarly type of ironworks was identified in the Guanzhong basin. This case study might have been very representative in addressing how the production was organized in a Han county setting. Second, since the site is situated within a trade network, the study of the iron foundry also improves the understanding about the transportation system as well as the political relationship generated by the moving of goods and raw materials. To facilitate the discussion below, this section will introduce the historical background of the site-complex. Then this section will move to the introduction to features and remains excavated to provide hints to contextualize the Taicheng foundry within the production system discussed above.

4.3.1 Discovery of the foundry and site complex

The Taicheng site complex is located at present-day Faxi 法禧 village, Yangling 杨凌 city (Figure 4.6). The site complex is lying on a flat terrace and overlooking the Wei River valley from the north bank. Local archaeologist had already identified the site as the location for the town of Tai based on bronze and ceramic vessels with the inscription of *tai* 斄 (a simplier form was written as 邰) that were found at the site and adjacent locations (Shaanxi et al. 1993; Shaanxi 1996). Taicheng was therefore named to refer to the entire site complex as local archaeologists believe that this location the town of the Tai county in the Han period, implying all remains dating to this time frame should be associated with the county town. Besides, in records published before (Lou 1993), archaeologists also claimed that remains of ramped-earth wall were remained on the ground surface. However, a more systematic survey conducted in 2011 (Figure 4.7), including pedestrian and auguring survey, did not discover either the rammed earth walls or architectural remains. Since the Corona image (Figure 4.7) taken in 1962 shows that the Wei River was much north than it has been recently, and the southern part of the orchard, where the Han is located, it is very likely that part or entire walled town has already been destroyed by one of the numerous flooding of the Wei River.

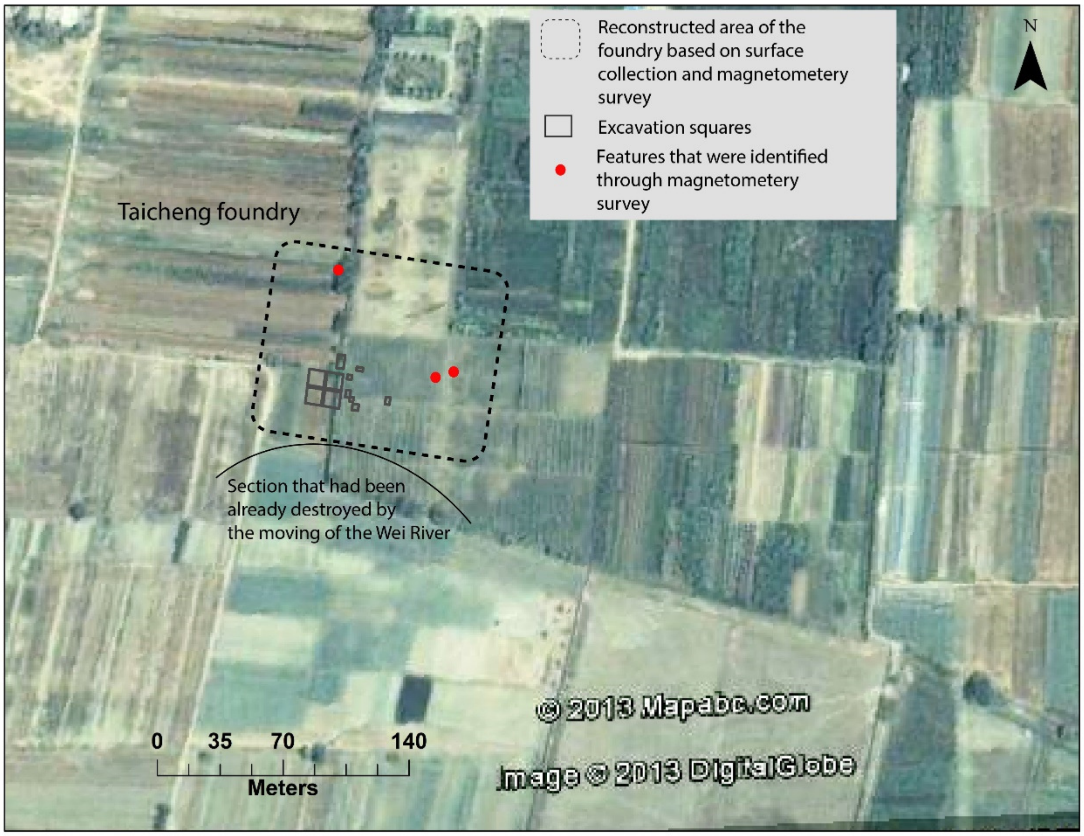


Figure 4.6 Estimated area of the Taicheng foundry

Although the site has not attacked much attention in previous archaeological work, Tai 邰 was one essential location that links to the ancestor of the Zhou people well before the establishment of the Zhou Dynasty. According to *Shiji*[58] and *Sijing*[59], Jianyuan 姜原, the mythical ancestral mother of the Zhou people, was a daughter of Youtaishi 有邰氏. More important, Jianyuan gave birth to a legendary figure named Houji 后稷, who later played an important role in educating and improving agricultural technique for Yao 尧. He also became an

[58] *Shiji* 4.112.

[59] *Maoshi zhengyi*, “Shengming”, 16, trans. Legge 1876: 303.

"agricultural official" and was therefore enfeoffed by Yao 尧 at Tai 斄. As a result, Tai could be viewed as the first settlement that Zhou people inhabited, and Houji was creditted as the starting point of the Zhou genealogy.

About 6 km to the north of Taicheng, an important proto-Zhou site named Zhengjiapo 郑家坡 was identified and discovered during the 1980's (Baoji 1984). Because it could date back to the Erligang period and is chronologically relevant to this early history of Zhou people (Lei 2010; Li 2006), the site was viewed as one of the most important discoveries associated with the debate about the proto-Zhou culture because Nonetheless, no systematic survey was conducted focusing on the settlement pattern of this important site. Nor was any connection between the Taicheng site-complex and Zhengjiapo site clear in archaeological records. In the Western Zhou period, the function and nature of the Taicheng site complex was obscure given the tenuous remains identified across the site. After the Eastern Zhou period, Tai belonged to one of the administrative units "county" governed by Neishi 内史 in the Qin period and then Youfufeng 右扶风 commandery in the Han period. But except the legendary connection with the Zhou first ancestor, Tai appeared to be just a normal and common county-level administrative units to which the authors of *Shiji* and *Hanshu* did not give much attraction.

Although the site was identified during the 1980's, no further archaeological works have been conducted at the site until 2010. The site complex became the focus of archaeological work because of the project Xi-Bo 西安-宝鸡 high-speed railway, which cut through the northern part of the site and destroyed part of the Qin-Han cemetery. This construction first led to a salvage project to excavation of the cemetery associated with the site complex. Given the numbers of burials identified through survey, the Shaanxi Provincial Institute then conducted a survey to investigate the structure of the settlement and identify residential area associated with the cemetery. The pedestrian survey covered more than 18 sq km, which eventually led to the discovery of the iron foundry. Within the survey area, the only because of the transformation of alluvial deposition and the transportation of the Wei River, Qin-Han remains were only sporadically identified through pedestrian survey; no features clearly related to the residential features have been found. Also, through pedestrian and augering survey, the archaeological team cannot identify any remains associated with rammed earth walls that were reported before.

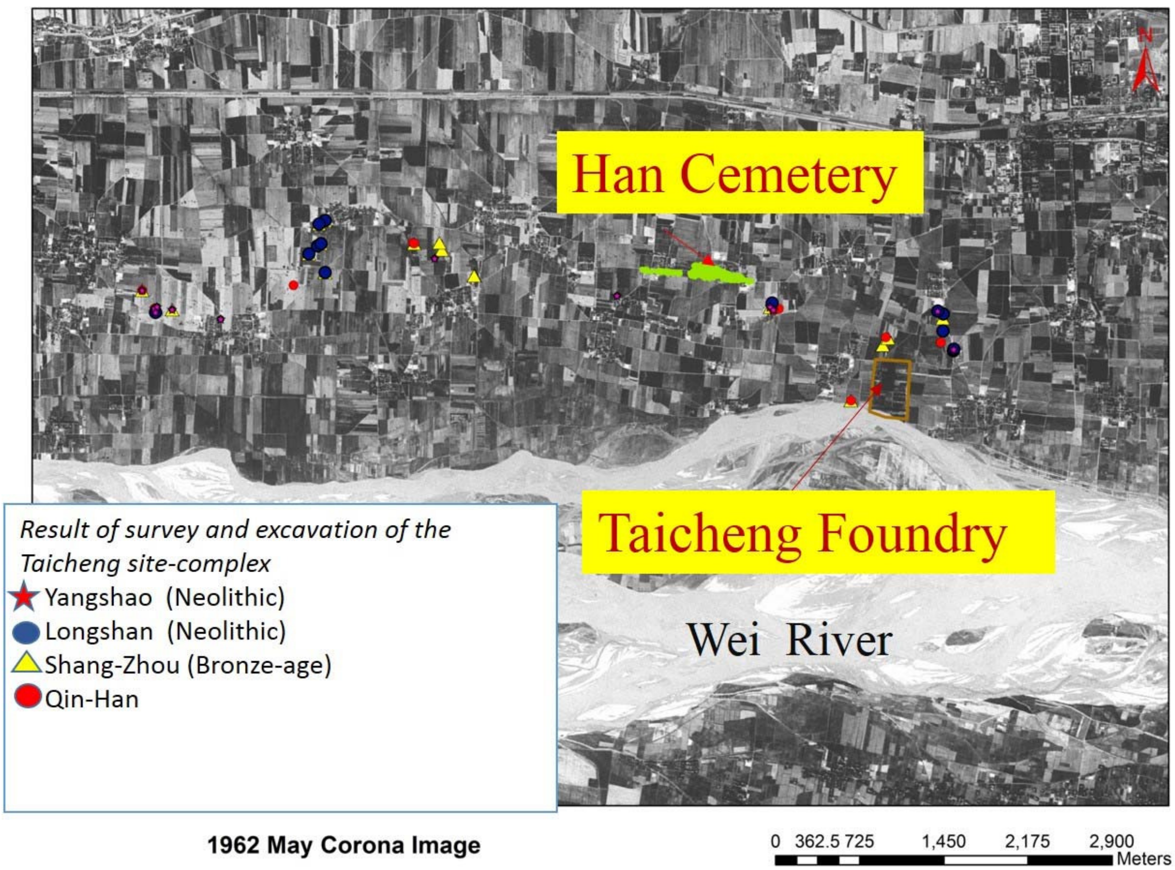


Figure 4.7 Map of the cemetery and foundry
(Please note that the southern part of the site had been destroyed by the Wei River, which is evidenced in this Corona image)

According to the excavation and survey, 295 tombs were found at the cemetery, which represent 90% of tombs in the entire cemetery. Most of them were small or medium size burials, primarily dating to the Early Western Han period. The information about these tombs will be explained further in Chapter 8. It is noteworthy that enclosing moats found inside the cemetery divided these burials into several different clusters. These enclosing moats might demarcate some interments that belonged to the same family or lineage. Furthermore, this cemetery is the largest collection of cemetery data outside Chang'an that has been found and excavated so far. The discovery and research on the site might provide an important line of evidence to reconstruct the social organization in small county level administrative unit.

Potentially, these individuals in the cemetery might represent just the residents just in the town of Tai county. In the Han period, the exact number of individuals administered by a county was dependent on the numbers of districts (*xiang* 乡). As I discussed concerning the structure of Han administrative districts in Chapter 3, during the Western Han period each village had about 1500 households on average (Yuan 2011). This number came from census data derived from Tianchang, Anhui, the southern part of the Empire in the Yangtze River valley. As the northern area of the Empire, Guanzhong in particular, had a higher density of population, the average population in Taicheng county should be at least not lower than this figure.

If it is the case, why does the demographic scale represented by the cemetery seem to be much lower than the estimated population of an average county according to excavated texts? Several factors would help to explain this discrepancy. First, a certain part of the population, such as those who are extremely poor, might not be able to afford a funeral ritual for the deceased. Second, certain migrated population would also be transported back to their original town for their funeral. In addition, it is likely that there might be other cemeteries associated with the town but not yet discovered. In previous work, considerable numbers of tombs also dating to the Qin and Han period were found at several locations around Yangling (Gao and Zao 1996). The scale of these cemeteries is still, unfortunately, unclear because of the lack of systematic works. In short, I suggest that 1,500 household might have been a reasonable estimation of the average population in the Tai county town, or the area represented by the Taicheng site complex.

Within the survey area, except for the iron foundry, no other direct evidence clearly related to craft production has been found (e.g., kilns). Nonetheless, the evidence of ceramic and bronze inscriptions possibly related to site might imply that the site was a ceramic and even bronze production center during the Qin-Han period. Besides the bronzes with the inscription of *Tai* 邰 that were claimed to be from the site (Lou 1993), ceramics dating to the Qin period with Taiting or Tai inscriptions were also found from Mei county. During the excavation, I also identified one piece of sherd with the inscription Tai from H1, a feature that dates to the earliest phase. In other words, Taicheng might have been a multi-crafting center manufacturing ceramic vessels and iron goods at the same time, similar to the cases of Yaoshang and Nangucheng discussed above. Since the scale of production might be very small, and no massive manufacturing waste had been produced, this type of site might not be easily identified through survey.

The iron foundry was located at the southern part of the site complex (Figure 4.7) sitting on the north bank of the Wei River. The area of the foundry is estimated to cover about 0.5 hectare (Guojia 2012), which has been further demonstrated by a magnetometer survey conducted in December 2013. Unfortunately, the major part of the iron foundry was underneath a modern orchard, and consequently has undergone limited excavation. The upper levels of stratigraphy (stratum postdating the Han, and perhaps part of the Han stratum) were destroyed and removed between the 1960 and 1970's. Even though the Taicheng foundry is very small in terms of its size, the archaeological investigation and excavation of the site have already generated the most systematic information about the structure of an iron foundry in the entire capital area.

4.3.2 Features and remains discovered from the foundry

A total of 39 features were found and excavated in 2011. The excavation area covers about 600 square meters. All these features should be associated with dumping or garbage pits; no features clearly associated with iron melting or refining have been found through the excavation. The excavation was conducted in two seasons in the same year. The first excavation opened an area of 500 sq. meters outside the orchard in April 2011. When the archaeological team realized the major part of the foundry might have been underneath the orchard, the team conducted a second excavation opening 6 test pits to target features identified through augering inside the orchard in July 2011.

Besides manufacturing waste, remarkable tile fragments have been unearthed, but no house foundations have been found so far. Also, at this stage, no features associated with kilns have been identified through the survey, augering, and even magnetic survey conducted in 2013. The production of casting molds must involve other infrastructure, such as a storage pit for preparing clay, but no features found are unmistakably associated with ceramic production.

Features associated with Han iron production usually were regular-shaped dumping pits. Some of them are relatively deep, for instance, H3, for specific purposes such as dumping large amounts of manufacturing waste. But for features that post-dated the iron foundry such as H6 and H7, they were very irregular and shallow. Major types of remains that were discovered include three major categories, manufacturing waste, faunal remains, and ceramic vessels. For the manufacturing waste, the assemblage includes slag, tuyeres, furnace linings, and casting molds. Left-over tools, either made of stone or iron, were absent from the site. The detail of these manufacturing waste and their natures will be introduced in Chapter 5. According to the evidence of molds, the major assemblage of final products only includes hoe and plough. Since molds could only provide the evidence for the goods that were made by casting, the final products of the site will be further investigated in Chapter 5. Certain numbers of faunal remains were found, and their analysis will be introduced in Chapter 6. As remains associated with daily life and consumption have been found at the site, the foundry might not have been a pure workshop—i.e., one in which workers came to a concentrated working area just for work according to the common definition of a workshop (Costin 1991).

During excavation, all remains were carefully collected, and dirt from all features were screened through mesh before dumping. No intact or well-preserved cutting or grounding tools have been found. Nor were any remains that would have been ores or ore material that have been selected for smelting. In other words, it can be certain that no iron ores or raw materials required the smelting procedure have been found from the excavated area. In Chapter 5, this idea will be further tested by metallurgical analysis of slag, but the assemblages of remains and distribution patterns that I will study in the following Chapters are unlikely to be skewed by the collection method.

4.3.3 Chronology and site formation process of the foundry

In the last section of this chapter, I will address the chronology of the site through ceramic vessels and tiles. This analysis provides the last piece of important information needed to reconstruct the entire site formation process.

The Qin-Han typology of both ceramic vessels and architectural materials from the Guanzhong Basin have been well developed in previous scholarship (e.g., Duan and Yu 2013; Han and Zhang 2011; Liu and Zhang 2007). This research provides a solid foundation with which to analyze the typology and chronology of the entire foundry. According to ceramic vessels (Figure 4.8, 4.9, 4.10) and other datable materials (e.g., coin models), all iron manufacturing waste should undoubtedly date to the Western Han period. But proto-Zhou remains from H10 and H11, which predate the Western Han period, were also identified at the same site. Besides, from H24, H6, H7, and H2, porcelain sherds were identified. According to the tile sherds found from the same contexts, these features must date to the Song (960-1290 CE) or Yuan (1271-1368 CE) periods, and these features belonged to later activities that destroyed part of the foundry site. Since proto-Zhou and Song or Yuan remains are completely irrelevant to the iron foundry, I will only focus below on the features or remains dating to Western Han or Warring States period below.

Below I select 10 features which have yielded relatively significant amounts of sherds with diagnostic characteristics (Table 4.1). Since the stratigraphy of the entire foundry is relatively simple, I can only determine the subdivision of phases according to the shape and morphological changes of vessel sherds. The assemblage of ceramic vessels from these features includes two major categories: *pen* 盆 (basin) and *guan* 罐 (jar). Other types of vessels include *weng* 瓮 (large jar) and *fu* 釜 (caldron), but these two types only include fragments and intact objects have not been found. The change of ceramic typologies seems to suggest that this assemblage of ceramics can be subdivided into 4 groups, representing three continuous phases. According to the distinctive characteristics of jar and basin, corresponding counterparts were often found in burial context (e.g., Shaanxi 2008a) dating to the Early Western Han period.

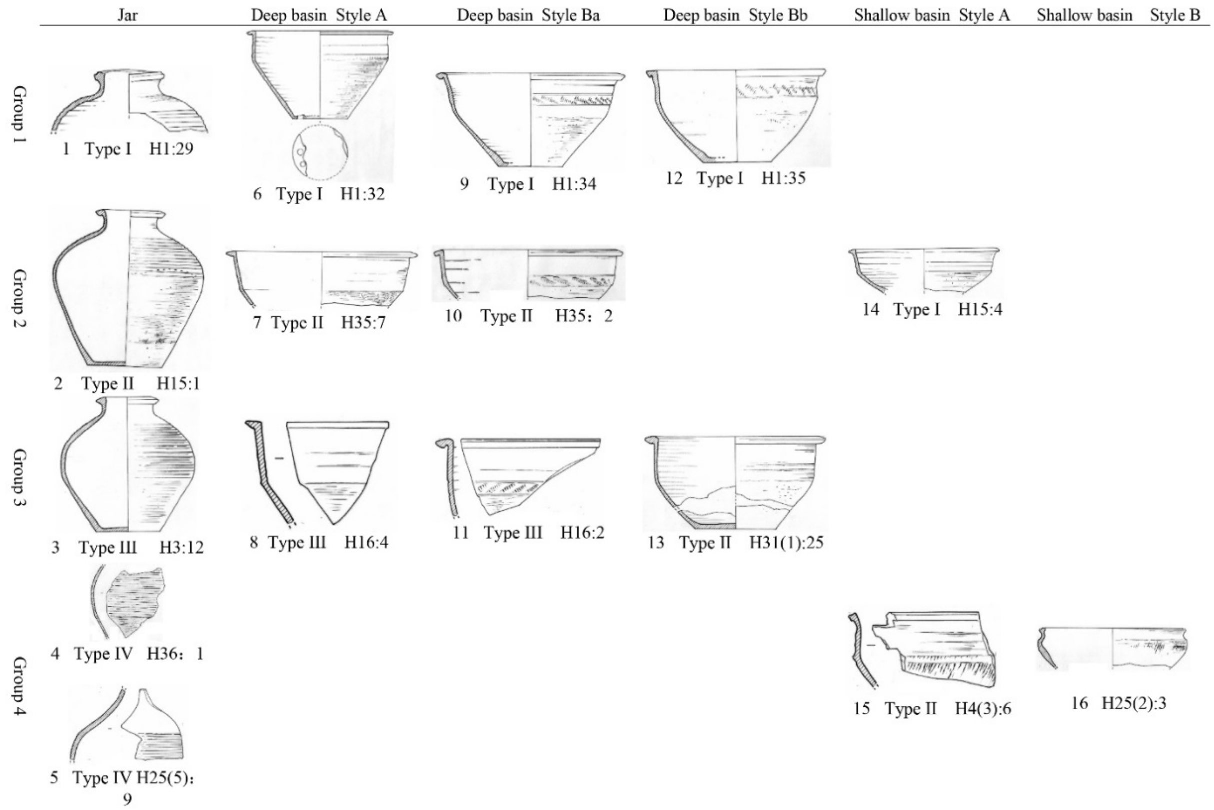


Figure 4.8 Typology of ceramic vessels (*Guan* jar and *pan* basin)

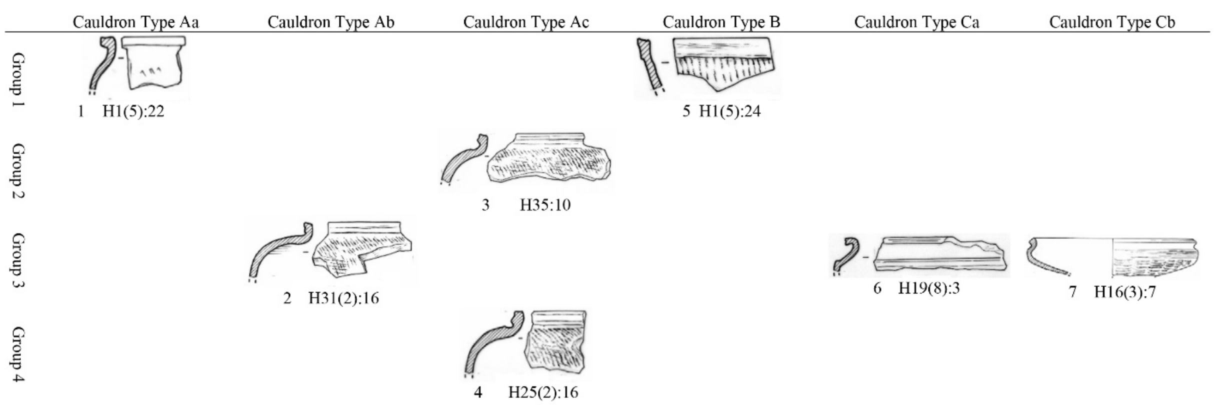


Figure 4.9 Typology of ceramic vessels (*Fu* cauldron)

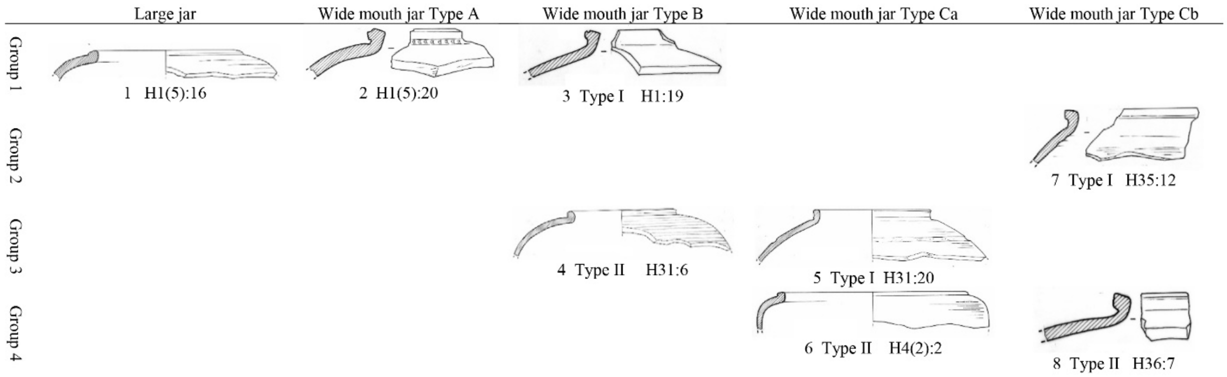


Figure 4.10 Typology of ceramic vessels (Large jar and wide mouth jar)

Table 4.1 Typology and corresponding phase of ceramic vessels

	Group	Phase	Deep basin Style A	Deep basin Style Ba	Deep basin Style Bb	Shallow basin	Jar	Large jar	Wide mouth jar	Cauldron Type A	Cauldron Type B	Cauldron Type C
H1	1	I	I4	I4	I1		I4	A2	A2,BI2	Aa2	B1	
H15	2	I	1			A I 1	II2					
H35	2	I	II3	II3	2		?1		CbI1	Aa2		
H19	3	II	II1		1							Cb1
H3	3	II	2	III1; II/III1			III2					
H16	3	II	III1	II/III1, III2					BI1			Ca1
H31	3	II	II3	II1; III1	II1		III1		BII1, Ca I 3	Aa2, Ab1		
H36	4	III	II1, III1		1		IV1		Ca I 1, CbII1			
H25	4	III	II2			B1	IV1,III/IV1			Aa1, Ac1		
H4	4	III		2	II1	A II 1		III/ IV1		Ac1	Aa1	

Another line of evidence comes from the coinage models identified from the site. A total of 3 pieces were found from H3 and H19 and used to manufacture banliang 半两 coins. As my colleagues have pointed out, the style and calligraphy of the banliang inscriptions and the size of coins all indicate these models were made during the reign of the Emperors Wen (180-157 BCE) and Jin (157-141 BCE) (Guojia 2012). Also, the only two coins identified from the site were both bianliang coins, and no wuzhu 五铢 were found from the site. Ceramic vessels and coinage models both securely situate the time frame of the iron foundry to the Early Western Han period, even though the end of the foundry might extend to the beginning of the Middle Western Han.

To better evaluate the sequence, I test it using diagnostic features on architectural materials: decorations of tile (Figure 4.11). Previous studies already demonstrate that the impression on the inner side of tile show chronological difference; the most diagnostic is that textile impressions usually appeared on the inner side of a tile after the reign of Emperor Wu, which eventually substituted those with "dot" impressions that were dominated in the Early Western Han period (Duan and Yu 2013; Liu and Zhang 2007). From the Taicheng site, significant amounts of tile sherds were found alongside other architectural ceramics such as bricks and tile ends. Both imbrex (*tongwa* 筒瓦) and tegula (*banwa* 板瓦) tiles were found from the site, but in the counting process the information of impressions on inner sides will be lumped together because the fragments of these two types of tiles are not easy to differentiate. In the graph below showing the percentage of different types of the impression and decoration on the inner inside, the statistic data clearly reflect this trend. In the first phase, the three features (H1, H15, and H35) have yielded quite a significant number of tile sherds with "dot" impressions; close to 20% of the tile sherds in the total assemblage were in the second category. It is of interest to note that the percentage of this category drops in the second phase, and the percentage of the first category rises more remarkably during the third phase.

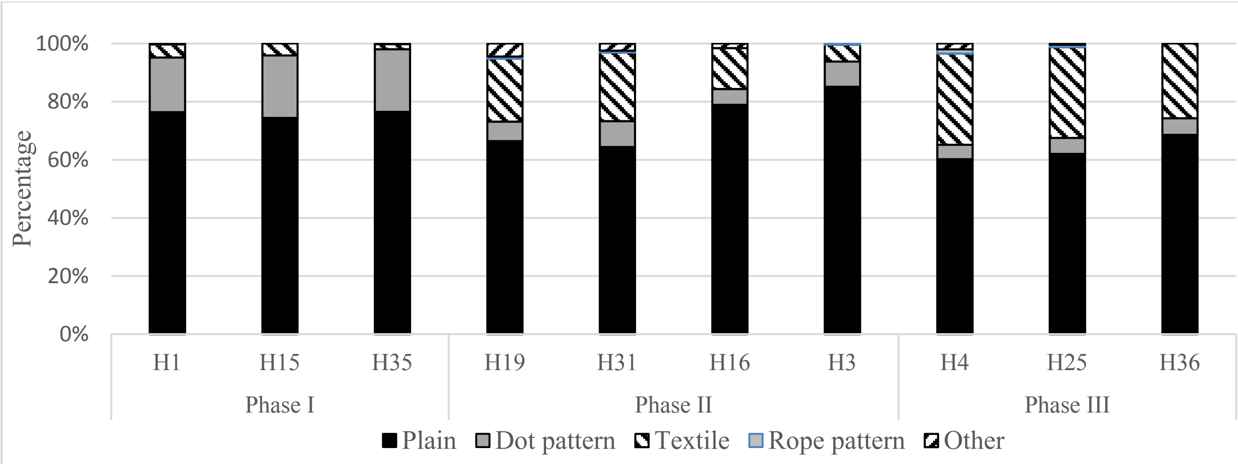


Figure 4.11 Percentage of various types of inner-side impressions on tiles

For the decoration on the surface of ceramics, the data also demonstrate certain meaningful patterns (Figure 4.12). For instance, there is a special pattern of stamp decorations and slip treatment on sherds from features belonging to the first and second phases, but their percentages drop remarkably during the third phase. It is important to note that the type of stamping decoration usually was found in published data dating to the Early Western Han period (Liu 1989). With the help of this line of evidence, the chronology employed in the dissertation should be relatively reliable and reflects the developmental process of the iron foundry.

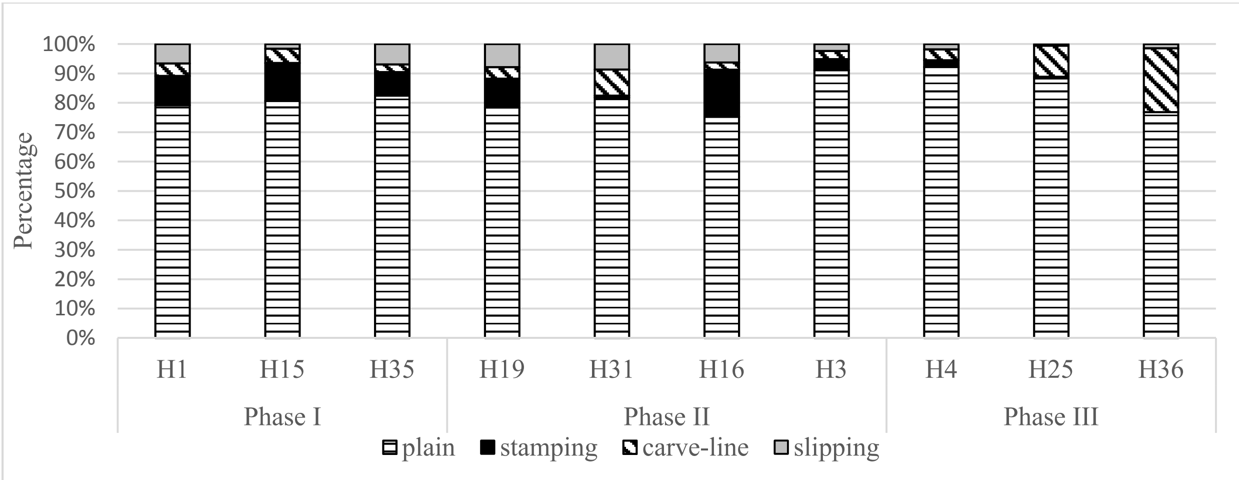


Figure 4.12 Percentage of various types of decorations on vessel sherds

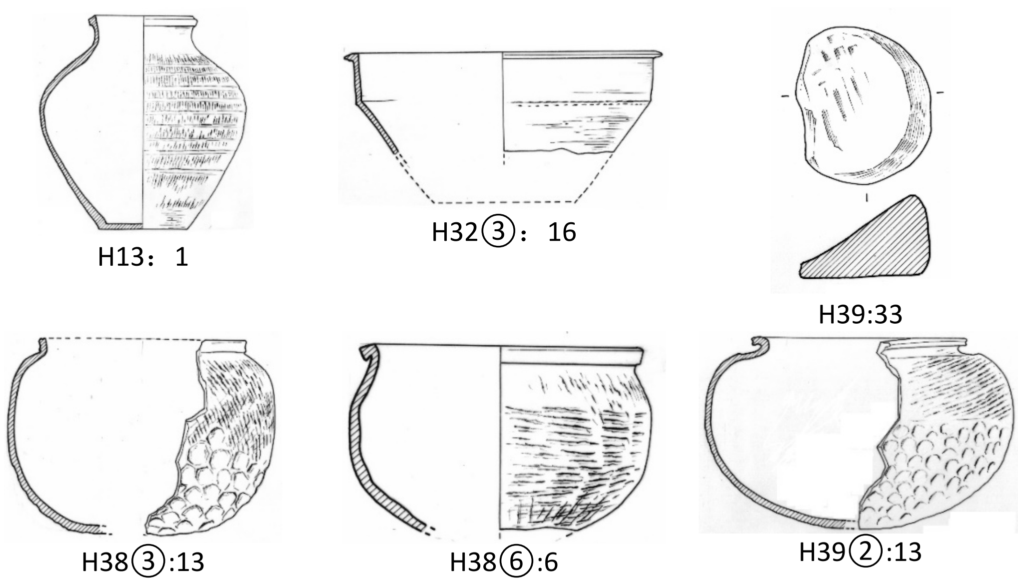


Figure 4.13 Ceramic vessels and tools of the Warring States period from Taicheng

According to these changes of shape, I and my colleagues suggest that the ceramic vessels might represent three phases, even though their date, in general, falls within the range of the Early Western Han period and might include part of the Middle Western Han. This time frame just maximally represents about 90 years. Besides, these three phases might indicate three major developmental stages of the foundry during the 90 years of its history. But this archaeological chronology does not necessarily mean the habitation duration lasted for the same time frame.

During this period, workers might conduct production only within a certain period in any given year. In addition, workers might commute to the site to manufacture iron but live in other areas after their shifts. In Chapter 6 and 7, I will employ zooarchaeological analysis and the ceramic vessel assemblage to investigate the habitation duration and seasonality.

In the excavation areas, there are at least 3 features, H32, H38 and H39, which clearly date to the Late Warring States period (Figure 4.13). Manufacturing waste has been recovered from these features, but the assemblage is completely different and demonstrates that the nature of the workshop was completely different during the Warring States period. Ceramic production waste was also discovered in these early phase features, including peddles, kiln remains, and over-fired products. During the Warring-States periods, therefore, the site was primarily used as a ceramic workshop which specialized in the production of *fu* vessel (Figure 4.13). In H39, significant amounts of ceramic sherds were found, and some of them show the evidence of over-firing. These vessels were broken and buried with burnt soil which might have been associated with firing activities in kilns. It also makes sense that, given the fuel, clay, and kilns required in ceramic production could have been used in the cast iron industry, the ceramic workshop might have been transformed into the a cast iron foundry after the founding of the Han empire. Since manufacturing waste associated with ceramic production has been identified, the iron foundry might have built upon or reused the facilities (e.g., kilns) to produce molds for cast iron. After the iron foundry was closed, probably due to the iron monopoly policies, the southern part of the site was destroyed by the cutting of the Wei River. Also, the western part of the foundry was severely damaged by human activities during the Song/Yuan period, which destroyed certain garbage pits; Han manufacturing wastes were re-deposited into these later features. For this reason, I will incorporate the re-deposited remains from disturbed features for the study of casting molds and intra-site distribution in Chapter 7.

In Chapter 7, the types of these ceramic vessels will be further discussed to investigate their implications for organization. In most features, habitation deposits were mixed with manufacturing waste including slag, iron pieces or scrap iron, tuyeres, furnace linings, and casting molds for agricultural tools in a dumping context. Based on the information of ceramics, the majority of manufacturing waste should also date to the Early Western Han period. According to all datable material, it seems safe to put the *terminus ante quem* of the foundry to early part of the Middle Western Han period (c.a. 130-67 BCE) and before the implementation of monopoly policy in 117 BCE. As mentioned earlier, the policy required that the private mining or casting activities either became part of the state-owned industry or were forced to be abandoned. In Chapter 5 and Chapter 7, I will discuss to what extent the assemblage of manufacturing waste and their distribution correspond to these developmental changes based on the preliminary analysis. In short, the Taicheng iron foundry appeared to be the type of local, small iron foundry in a county level of settlement. and the site complex might have been associated with the town of Tai county. The iron foundry had been used for about 100 years, but it dates to the critical period before the implementation of monopoly police.

Summary

To sum up, the unique geological characters of the Guanzhong Basin not only provide natural protection for the capital but also facilitate the communication with different parts of the Han Empire through pathways and networks. Because of the rich loess deposits, the Guanzhong Basin was favorable for agricultural production. Large-scale canals during the Qin-Han periods were one of the many examples constructed to engineer the natural environment and to increase the agricultural yield. Also, as the Guanzhong Basin, especially Chang'an sits at the center of the intersection of major pathways to the Middle Yangtze River, Middle Yellow River, northern-eastern China, Chengdu basin, and Hexi corridor, the Guanzhong was well-known for being "the hub of wheels"[60] in the market exchange of commodities from different regions. Furthermore, the moving and relocation of migrants from the eastern part of the Empires, servants of elites, officials, labors, etc., into Guanzhong further integrated the capital and nearby mausoleum towns to the cluster of urban centers with the highest population density in the entire Empire.

The large population certainly boosted a substantial requirement for food. Yet, a large portion of arable lands to the South of the Wei River nearby Chang'an was claimed by the Emperor as the royal Park. As a result, the transportation of staple food collected from the eastern part of the Empire and various parts of the Guanzhong Basin to Chang'an were one of the key issues in the administration system. Certain warehouses and transportation canals were constructed in order to speed up the moving of resources and prevent the network being interrupted. Thus, Guanzhong was not only a symbolic and cosmopolitical center of the Han Empire; it also served as the major transportation or transfer center at the hub of the network consisting of many warehouses, channels, and pathways. Also, Guanzhong sits at the junciton of transportation networks for food and various types of commodities. Intensive transportation of goods as well as raw materials, including iron, undoubtedly existed in the Han period given the high density of population in the basin and large urban centers (mausoleum towns).

[60] *Shiji* 129.3261, trans. Swann 1974[1950]: 437

But Guanzhong was no more a major craft production center than a ritual, political, military supplies, agricultural production, and even minting or financial center for the entire Han Empire. The Guanzhong Basin or even the mountains at the edges of the basin lacked resources (copper, iron, etc.) essential to the Empire. Nor were extensive remains associated with craft production found in the basin. In the entire region, the largest workshop is the Shanling minting site, but archaeological discoveries show that the site manufactured no other goods except coins or some other elite bronze products. The discovery of the craft production remains also demonstrated that, except the large bronze mints at Shanglin Zhongguan, remains found within the basin were usually associated with small scale of production. Even the craft production remains were only related to small scale chariot-fitting manufacture. The iron industry, for instance, did not seem to be highly developed and in a big scale in comparison with other industries. According to archaeological data discovered so far, Guanzhong did not appear to be a craft production center for goods that were required in daily lives such as iron agricultural tools.

For this reason, I believe, the Guanzhong Basin was an ideal place for the study of iron commodities through the framework proposed before, since every element associated with commodities exchange, namely the market, transportation network, waged labors, and monetary system, already existed. What is critically unknown is how resources were obtained from outside and how products were distributed through the network or manufactured in a local context. The case study of Taicheng and related study of iron tools from different cemeteries, therefore, provides an important piece of evidence to investigate how the market system reconcile the large social demands and the lack of supply. So far, Taicheng is the only foundry where careful excavation and data collection have been carried out in this political heartland. Given the fact that the scenario of the iron industry in this crucial area is almost unknown in previous scholarly works, the study of the site can undoubtedly fill an essential gap in the understanding of this important industry.

CHAPTER 5

MANUFACTURING WASTE, TECHNIQUES, AND CHAÍNE OPÉRATOIRE

Introduction

The majority of manufacturing remains from Taicheng is discovered in the context of garbage pits. Preceding analytical work is necessary to facility the classification and identification of their functions. Results of analyses can serve as the foundation to reconstruct the *chaîne opératoire* (i.e., the procedures or steps in the production process), which is indispensable for understanding the spatial organization of the foundry based on the inventory of manufacturing waste in each feature.

In order to facilitate the discussion below, this chapter will first introduce the principles and mechanism of procedures (i.e., iron smelting, iron melting, and iron refining) in iron production in general. Since slag preserved the best line of evidence to address the technique of iron production, section 5.1 will overview and discuss the identification standard of slag which was generated by different production procedures. In 5.2, I will discuss the types of manufacturing waste in more detail and their variation in each category from the entire excavation, including molds, slag, *tuyères* and furnace lining, and iron pieces. In the introduction to casting molds, I will calculate the numbers of products that could have been produced by these casting molds to investigate the scale of production. I will also discuss the mold-making processes according to the traces and evidence left by mold production. This discussion of production processes is necessary to calibrate the understanding of the metric measurements that will be introduced in Chapter 7.

In the following sections 5.3 and 5.4, I will employ metallurgical analytical techniques to analyze collected slag samples and iron pieces according to the categories introduced above. Even though manufacturing waste from the site includes a wide range of variety and, perhaps, by-products from different steps, in this chapter I will focus primarily on slag-related remains and iron pieces, given the fact that their natures and related technological procedures are always not certain. In addition, metallurgical analysis through microscope and SEM-EDS can usually generate enough evidence to address their natures and investigate the production sequence of the site, which may not be the case for *tuyères* and furnace linings[61]. In order to direct the research focus to tackle the most critical issues about the nature and organization of the iron foundry, remains other than slag and iron pieces will not be subjected to scientific analyses at this stage. To clarify the overreaching goals of this chapter, the essential issues that I aim to address through metallurgical analyses are:

#1 Do slag remains sampled for analytical study show that they were generated primarily by iron melting activities?

#2 What were the techniques (e.g., which type of flux) employed during the process of making pig iron?

#3 Whether other procedures (e.g., smithing and refining) were represented by manufacturing waste?

[61] For tuyeres and furnace linings, the analysis has to be conducted together with petrographic analysis and XRD in order to get more meaningful data about the raw materials selected and other technical aspects such as refactorability.

#4 What were the natures of iron pieces found at the site? Are they all probably related to the by-products generated by iron melting? Or some might represent raw materials (e.g., decarburized iron bars) or discarded iron tools?

5.1 Introduction to Iron Techniques and Analytical Approaches

Before introducing the analysis and identification standards, I will explain the principle of the two major ways producing iron, i.e., bloomery iron and cast iron, and related terminology. Because of different mechanisms, the chemical compositions and microstructure generate different assemblages of patterns or indicators. Early research on iron slags has already pointed out ways to differentiate different types of iron smelting processes, particularly focusing on bloomery iron production through slag and slag inclusions in iron objects (below and in other chapters I will use the abbreviation SI for "slag inclusions"). More recently, research on iron slag has tried to pinpoint the provenance of resources (Desaulty, et al. 2008:67; Paynter 2006). Since standards and criteria have been intensively discussed in the literature (Huang 2008; Miller and Killick 2004), this section will summarize standards to lay down the foundation for identifying the techniques employed and reconstruct the operational chains.

5.1.1 Principles of iron smelting and slag forming

Iron smelting, i.e., reducing iron ores to metallic iron and getting rid of impurities/non-reducible compounds such as silicon and aluminum (below all chemical elements will be represented by the alphabetic symbols such as Si and Al) in gangue with carbon monoxide gas formed by burning charcoal (Gordon 1997), is the first step in the production process. This procedure can be done by two different approaches. The first usually is called a "direct process," which involves a relatively small furnace or hearth to reduce iron ores in a solid stage and a slightly reducing environment and relatively low temperature. The final products were called "bloomery iron," which was usually the first attempt to employ iron-smelting techniques to produce objects around the world. In many regions such as northern and western Europe, the technology continued for several hundreds of years until the arrival of the blast furnace and refining techniques. During the process, non-metallic minerals, primarily silicon, form "fayalite-wüstite" eutectic-constituent with iron, the major part of bloomery iron slag corresponding to a relatively low melting point. As a result, the formation of flowing slag can get rid of the undesirable non-metallic elements. Slag formation is also necessary to pick up ash in the combustion zone and protect iron to be oxidized in the combustion zone (Charlton, et al. 2010; Charlton, et al. 2012).

As iron made by this method is never completely molten, slag cannot be completely separated and is trapped in the matrix of iron. Thus, the typical microstructure of bloomery iron slag consists of fayalite, dendritic wusite, glass, charcoal, and incompletely reduced iron ore, hercynite, and leucite (Gordon 1997; Huang and Li 2013). Chemically, since certain non-metallic elements (Si, Al, Mg, K, and Ca) cannot be reduced in the process, the typical bloomery iron slag in general will have lower Si/Fe ratio than the slag generated by blast furnace, cupola furnace or indirect method for making refined pig iron. Also, since bloomery iron slag is self-fluxed and the smelting process does not necessarily require additional flux (usually containing Ca or Mg), in general slag may have lower Ca and Mg ratios. Correspondingly, objects made of bloomery iron will have lots of large-sized non-metallic SI in the metallic matrix representing the characteristics and chemical compositions of bloomery iron slag discussed above. Even in the hammering and forging processes, SI in bloomery iron objects will be very difficult to remove and then present in the microstructure.

In contrast, iron production or smelting in ancinet China was more commonly conducted by another approach using a so-called blast furnace, which refers to a tall furnace with a long shaft that can generate enough heat and a high reducing environment (the ratio of CO:CO2 is more than 9:1) for iron smelting. During this process, metallic iron and other non-reducible compounds (I use the abbreviation "NRC" below) can almost be reduced completely. As a result, the majority of impurities in ores will go into slag through the smelting process, and SI are rarely found in cast iron objects.

For the operation of blast furnace, adding flux (usually limestone or dolomite) in relation to Si and Al in ore is necessary. Since silica and alumina have a stronger affinity for calcium and magnesia than they have for the iron, and in consequence double silicates of lime and alumina or magnesia and alumina are formed compounds which contain very little iron (DC 1929). The microstructure of cast iron smelting/melting slag shows relatively homogeneous glassy structure with small skeleton crystals of fayalite. In addition, a cellular or vesicular structure resulting from bubbles of gases that were dissolved in the molten slag is usually identified. High Ca crystalline products (e.g., wollastonite) due to the slow cooling rate and small iron globules (with diameter 0.01-2.0 mm across)—which are high in Si while low in Al—with cast iron microstructure are also commonly found.

5.1.2 Principles of pig iron decarburization and differences between refining and blast furnace/cupola furnace remains

Cast iron can be produced as a by-product of the blommery process. But cast iron is not an ideal material for making tools because of its brittleness. Cast iron can only be useable following the development of refining or decarburizing, which can change cast iron into wrought iron and steel. Previous studies show that these two approaches were adopted in Early China during the Warring States and Early Han period respectively to improve the quality of cast iron products (Han and Chen 2013). The first one, decarburization, involves annealing cast projects in an oxidizing environment for a long time (e.g., 1 or 2 days) to reduce carbon contents in iron objects. Final products of this approach include malleable iron and decarburized steel, which had been widely adopted since the Middle Warring States period (Han and Ke 2007). The microstructure of these objects consists of ferritic-pearlite or ferrite. SI are rarely found in this type of products, but shrinkage holes or cavities are often identified. In some cases, incomplete carburized cast iron structure could be found in malleable iron due to the incomplete carburization process.

The second approach is refined pig iron, which was decarburized in the molten stage through stirring, a process called *caogang* 炒钢 in Chinese. Since this approach involves two separate steps to produce wrought iron or steel, this approach is also called the "indirect method", which was evidently employed in ancient Chinese iron production by the latest 140 BCE (Beijing & Xuzhou 1997; Chen and Han 2007). When pig iron was molten in a charcoal fire under oxidizing conditions, carbon and silicon will be out to convert blast furnace-produced pig iron to wrought iron (Gordon 1997). Although pig iron usually contains very few impurities or inclusions, finer will add flux as well as sand or hammer scale to form slag for several reasons (Wagner 2008). First, the iron-oxide rich slag can help remove carbon and the phosphorus from the metal. Adding sand and flux can facilitate the formation of Ca-rich phosphate and prevent the P element, which is notoriously impacting the quality of iron products by increasing its brittleness, returning to the bloom. Second, the formation of low-melting-point slag can pick up ash of burnt fuel and other impurities on the surface before hammering.

In addition, during the refining process Si, Al, Mg, K, derived from pig iron, furnace lining, flux, and fuel, cannot be reduced, Dillmann and other scholars (Desaulty, et al. 2008; Dillmann and L'Héritier 2007) suggest that the ratios can serve as a signature to identify products that were made from the same sources, furnace, fuel, and flux. In terms of microstructure, SI in refined pig iron objects can include a wide range from glassy inclusions to compounds including iron oxide, fayalite, and other non-metallic elements such as Si, Ca, and P, depending on the thermodynamic conditions in the furnace. In addition, several authors have already pointed out that microstructures of refined and bloomery slag include both fayalite, abundant wüstite (or magnetite), and glass, except the slag formed by the later process would occassionally include incompletely reacted ore and other minerals (e.g., spinels) (Gordon 1997). Also, the typical structure of a refined iron object usually consists of ferritic regions with bulky wüstite-rich slags alternated with pearlitic zones containing a modest amount of slender FeO-poor glassy slag. Therefore, refined iron slag or SI is difficult to distinguish from those of bloomery iron, especially if the object was heavily worked.

For this reason, the identification standards between SI in refined iron and bloomery iron has been discussed substantially in literature (Buchwald and Wivel 1998; Chen and Han 2007; Dillmann and L'Héritier 2007; Disser, et al. 2014; Yang, et al. 2014). During the indirect process, refined pig iron means that liquid stage cast iron is stirred in furnaces in order to let the carbon in cast iron become oxidized and to create low-carbon wrought-iron. SI were thus trapped in the metallic matrix during this process. Consequently, SI in refined pig iron usually are smaller and thinner in size and shows a higher degree of deformation in comparison with direct process products. In addition, sand from the casting bed is commonly adhered to the pig and slag (Gordon 1997) during the process of decarburizing pig iron.

This mechanism is important in understanding the structure of slag. For bloomery iron, the chemical signals come from ores (primarily Si and Al), reaction with technical ceramics such as furnace lining and tuyères (containing high concentrations of Al_2O_3 and SiO_2) (Veldhuijzen and Rehren, 2007), ash of charcoal (containing high concentrations of CaO and K_2O), and fluxes that were added to promote the yield (Ca, Mg, and sometimes Mn) (Charlton, et al. 2012). These elements were not entirely reduced and enter into slag along with SI trapped into the bloom. But for the indirect method, since NRC from gangues are basically reduced and enter into slag during the smelting process, NRC in refined pig iron (SI, Al, K, Mg, and Ca) is derived from the furnace lining, fluxes, and flue but not the pig iron, which has been removed during the smelting.

After eliminating the abnormal SI data that are caused by local concentration through hammering and adding additives (e.g., sand), Dillmann et al. (Desaulty, et al. 2009; Dillmann and L'Héritier 2007; Disser, et al. 2014) suggest that the ratios among NRC should exhibit certain patterns distinctive from direct process SI. Through using logistic regression to calculate SEM data, they calculated and identified the differences in corresponding probabilities of the Logit value from an indirect or a direct process. They also used iron objects from a French cathedral with clear dating and provenance information to test the formula and discovered that this approach is very robust. By employing this approach, the research team found out that Al, K, and Mg elements in refined pig iron slag have lower quantities than those in direct-process products, while iron oxide will be relatively higher given the fact that the environment is relatively oxidized. Therefore, this method can provide a powerful supplementary tool to substantiate the identification only based on the microstructure and relative ratios of elements.

One issue not thoroughly discussed is the distinction between blast furnace slag (smelting slag) and cupola furnace slag (melting or remelting). In fact, the distinction between these two types of slag is very murky due to the fact that the environment and types of additives are very similar. Modern studies on cupola slags also confirm that the cupola furnace slag is very similar to blast furnace slag (smelting slag) in terms of its chemical compositions and microstructure, except the crystalline minerals. According to the study of modern slag, in cupola furance slag (air-cooled) the most frequent minerals are wollastonite (the mineral consists primairly of Si and Ca) and fayalite, while the crystalline minerals of blast furnace slag usually are mostly melilite and include a wide variety (e.g. gehlenite and akermanite) (Baricová, et al. 2010). In addition, cupola furnace slag can range from acid to basic, but blast furnace slag usually is basic (i.e., the ratio of [CaO+MgO]/SiO2 is higher).

In modern iron industry, a blast furnace is primailry fueled by coke. Therefore, fluxes containing high calcium and alumina are indispensable during the smelting process in order to prevent P entering into the metal phase. But in the context of Han China, only charcoal was used during the smelting and melting process. In this case, the major purpose of fluxes is to form compounds with silicon so as to reduce the melting point and increase the yield, which means this modern example may not be entirely applicable. Because neither iron ores nor ore processing tools were found from the Taicheng site, the archaeolgoical context in this case strongly suggests that the foundry very likely only served as a melting foundry site.

For this study, the characteristics of major types of slag are summarized below (Table 5.1, 5.2):

Table 5.1 Standards of the identification of different types of slag

	Cast iron slag	**Refined pig iron slag**	**Bloomery iron slag**
Microstructure	glassy matrix+ small cast iron droplets	fayalite+magnetite (or wüstite)+ glassy matrix	fayalite+wusite+ glassy matrix
Chemical composition	high in Si and Ca; Fe is very low; incompletely molten sand, flux, and hammer scale	high in Fe, Si, and Ca. Other minerals such as Al and Mg were relatively few;	high in Fe and Si; Other NRC such as Al, Mg, and K is relatively high

Table 5.2 Standards of the identification of different types of iron objects

	Cast iron	**Refined iron**	**Bloomery iron**
Microstructure	Eutectoid white cast iron (pearlite+cementite)	Ferrite or ferritic-pearlite structure. High P band-structure or ghost structure	Ferrite or ferritic-pearlite structure
Inclusion	Absent or extremely few	Containing elongated and highly deformed SI.	Containing large sized SI

5.1.3 Sample preparation and analytical techniques

During the fieldwork, I classified the manufacturing waste into several categories based on visual characteristics and distinctions. Samples were then collected to represent these categories for scientific analyses. This visual classification might not have fully distinguished types of artifacts (e.g., refined pig iron objects) that I need to identify for this study. Nonetheless, the screening process was still effective in helping to find out special remains for a particular analysis. For iron objects, they were also classified first into two categories. Since the analysis aims to identify the natures of remains, the metallurgical analyses aim to address remains that are unclear and unable to be identified only based on visual characteristics.

After basic recording (descriptions and photography) and sampling, slag and iron samples were mounted in epoxy and processed by classic grounding and polishing procedures. Then iron samples were etched with 3% ferric-nitric acid, and photomicrography documents were taken for recording important microstructures. For slag samples with large iron pills, samples were etched before taking photomicrography documents in order to identify the eutectic structure. After taking microphotography and identification of basic structure and types, samples that are potentially related to refined pig iron (a total of 3 samples) were selected to subject SEM-EDS analysis. For this study, I used the SEM equipment from CNS center at Harvard.

5.2 Assemblages and Classification of Manufacturing Waste

No complete or *in situ* furnace was found during the excavation, and all types of manufacturing waste were found mixed in garbage pits. Consequently, from the same context remains associated with different procedures were found together. This context imposes a critical challenge to the study of manufacturing waste. To address this issue, I will first introduce the basic categories of major manufacturing waste in order to present a brief understanding about to which types of procedures they might belong. During the fieldwork, the classification of manufacturing waste can facilitate recording as well as identifying samples for metallurgical analyses. After classification, I recorded the weight of these categories in order to quantify all excavated data.

5.2.1 Slag and slag-related remains

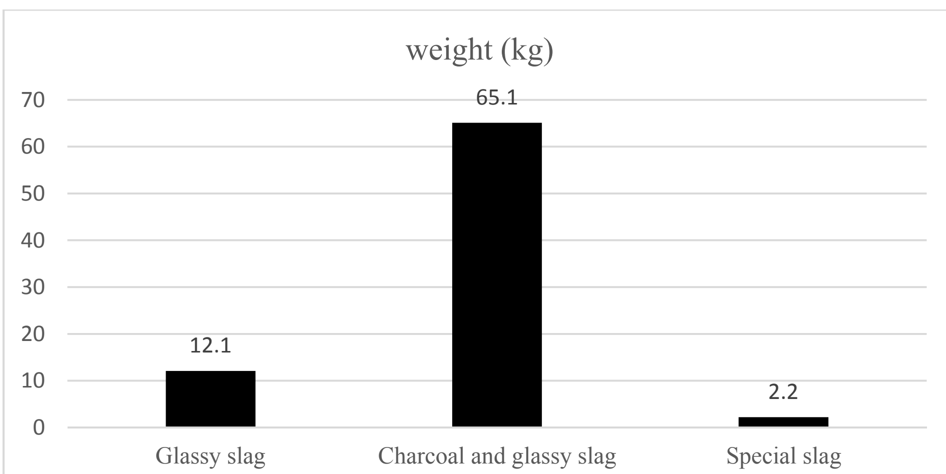


Figure 5.1 Total weight of different types of slag

Although cupola furnaces do not directly reduce ore, their operation will still generate large amounts of waste. The amount of slag is often related to the types of scraps that were used as charge. For instance, light corroded scrap iron tends to generate less slag in comparison with heavily corroded scraps. From Taicheng, close to 90 kg of slag or slag related remains (Figure 5.1) were identified from features. Remains belonging to this category, in general, include several types (Figure 5.2):

1) Glassy and vitrified slag

This type of remains is pure glassy slag. They are highly glassified, with or without flowing-texture on the surface. The highly vitrified one usually are black, but most are white, grey, or greenish, depending on the cooling rate and the elements contained. In general, they belong to by-products of cupola furnace melting.

2) Charcoal or charcoal with "trapped" slag and iron liquid chilled by blast

This type of remain belongs to the same processes of the first type of slag. In general, it is a mixture of incompletely burnt charcoal, cast iron, and glassy slags. During the melting process, scrap iron (or iron ingots), fluxes, and fuel were mixed before dumping into the furance. Molten slag and cast iron liquid have to pass through the combustion zone in order to accumulate at the bottom of a furnace. If these two types of materials are trapped in a charcoal, they cannot be burned anymore and need to be removed out of the furnace after the operation. Some items were just a mixture of slag and iron pieces, probably bear iron that was formed in the furnace when liquid iron was cooled down and consolidated inside the furnace. This category in general was the type of "left-over" remains in the chamber of furnaces after melting.

3) Special slag

After identifying the first two categories, I put slag that is not glassy and does not show the visual characteristics of glassy cupola furnace slag into the third category—special slag. The numbers of slag in this category are much fewer than other categories. Some may just belong to furnace linings with relatively low vitrification degrees. But at least two piece of slag belonging to this category are clearly associated with refined pig iron production according to metallurgical analysis, which I will introduce in section 5.3

Type 1 Type 2 Type 3

Figure 5.2 Typical examples of three types of slag identified at the Taicheng site

It is importan to note that the natures of remains classified based just on visual characteristic are not multually exclusive. A piece of slag that I classified as type 2 (71147:2), for example, was assoicated with the refining process (see section 5.3). Also, some pieces of special type slag belong to incompletely molten furnace lining. But given the significant volume of slag identified, this type of first-step screening is necessary in order to identify slag that might show special characteristics other than cupola furnace slag. In addition, given the total amounts of special slag and slag associated with refined pig iron production identified, it seems safe to suggest that slag related to cupola furnace melting is the most dominate category in the assemblage.

5.2.2 Tuyères

Tuyères are the blowing pipes to blast air into the combustion zone of a cupola furnace. In addition, iron smithing and pig iron refining also need to use tuyères, but their size might be significantly different from the first two types. From Taicheng, at least four major types of tuyères have been identified from the excavation, which are different in terms of the material, ways of installation, and, perhaps, function (Figure 5.3; for the summary see Table 5.3). The first type is the tuyère with lots of straw-tempered traces but containing very little coarse quartz (Figure 5.3: type 1). Well-preserved ones even have rope-impressions on the surface. The heated-surface was evenly distributed, and some pieces even preserved glassy or vitrified surfaces. Special cases are primarily identified in H16 (e.g, H16y73). The heated area of tuyères is limited and constrained like a long strip from one end extends to another end of the pipe. Another special case comes from H7y8 with a U-shaped structure on the top of the tuyère. Also, according to the reconstructed radius, this type of tuyère is relatively large and between 22~28 cm (Table 5.3). Therefore, Type 1 may have been used through reassembling multiple components together as a top-blasting type tuyère to blast air to a furnace in a top-down position.

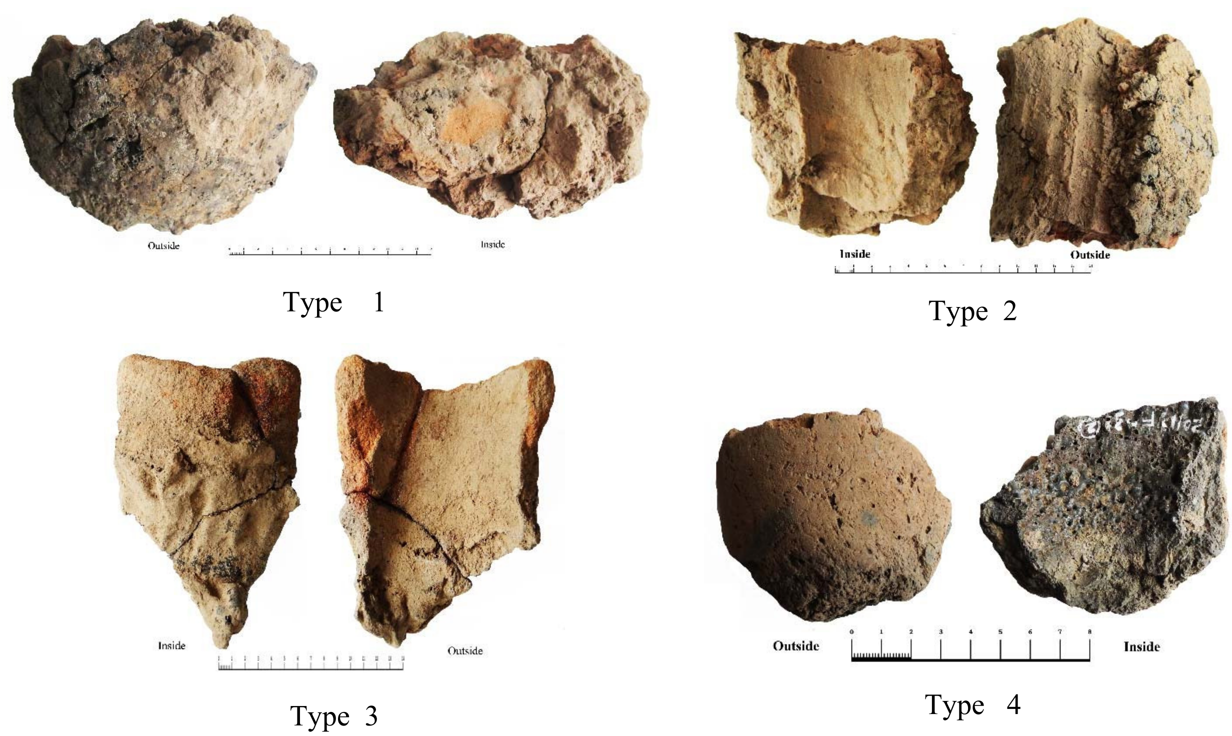
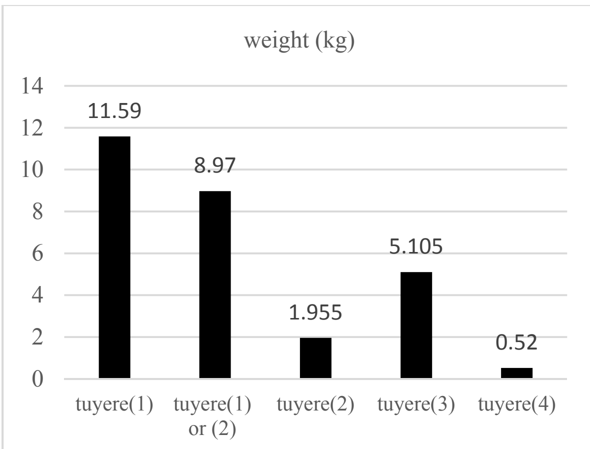


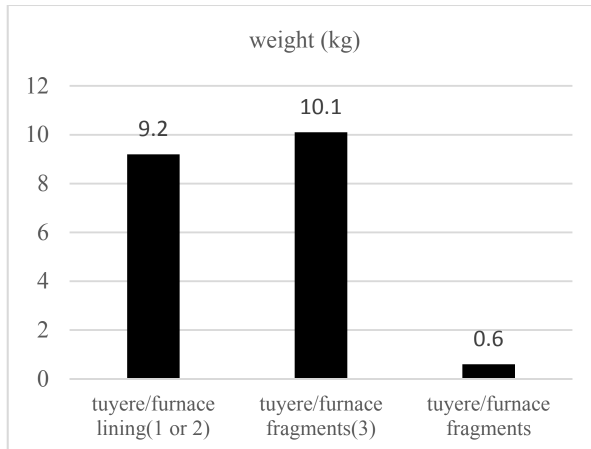
Figure 5.3 Types of tuyères identified at Taicheng

Table 5.3 Description about the types of tuyères identified at Taicheng

	Materials	*Blasting method*	*Radius (cm)*
Type 1	Straw-tempered clay and fined sand	Top-blasting	22-28
Type 2	Straw-tempered clay and fined sand/with clear groove-shaped structure	Top-blasting	Inner radius 9.2 Thickness 2.5
Type 3	Coarse-sand tempered	Side-blasting?	Outer radius 11
Type 4	Fined sand tempered with fined sand/ showing internal-burning	Top-blowing	Unknown



A



B

Figure 5.4 A) Total weight of all tuyère; B) Total weight of remains that belong either to tuyère fragments or furnace lining

The second type of tuyères was made of a similar type of materials: fine sand and straw-tempered clay with very few coarse sand tempers. The major difference between Type 1 and 2 is that the external surface of the pipe shows groove-like impressions (Figure 5.3: Type 2). The pipe is not straight and curves to a certain extent like a horn. The outside of the tuyères (e.g., H34y95) were strengthened by a protective layer using the same material of Type 1 tuyères. For certain pieces, it is difficult determined whether they belong to Type 1 or Type 2. According to the curve shape of the type, very likely Type 2 also belongs to the top-blasting type, but the reconstructed diameter of this type of tuyères is about 9 cm (inner radius) and appears to be relatively smaller than Type 1. Although pieces that are specifically identified as type 2 tuyères are relatively few, fragments belong to either Type 1 or 2 were the major type of tuyères came across at the site. The total weights of these two types are much higher than the other two types.

The third type of tuyères was made of coarse quartz-tempered clay with very few inclusions of straw-tempered clay. The texture of material is very similar to that for making plow molds. Different from Type 1 and 2 tuyères, the heated or vitrified zone usually concentrates at one end of a tuyère, while the other end of the tuyère does not present any trace of intensive heating or vitrification (Figure 5.3: Type 3). This type of tuyère is clearly associated with cupola furnace melting, but I suspect that tuyères of this category might be inserted into the combusted zone of the chamber through the wall of a furnace on the side. In terms of diameter, the Type 3 tuyère appears to be relatively smaller in size in comparison with the type 1 but similar to Type 2 tuyère. Fragments of coarse sand tempered remains with vitrification signs, which might be either tuyère fragments or furnace lining, were also quite commonly found, even though the total amount is smaller than the first two types.

The last type is particularly special because the wall is relatively thin, and its size is very small (Figure 5.3: Type 4). In addition, only the internal side or surface of the pipe shows signs of burning or vitrification, instead of the external side. Accordingly, this type of tuyère was more likely used for iron smithing instead of iron melting or smelting. Figure 5.4 presents the total weight of all types of tuyères and tuyère related material. Clearly, Type 1 seems to be the most dominant type of pipes in the assemblage in comparison with tuyères made by different materials.

5.2.3 Furnace lining and fragments of furnace wall (burnt soil)

A furnace lining or furnace wall was made of materials more or less the same as tuyères. They are identified when the entire piece is relatively flat or only the inner-side of the material was vitrified. Furnace lining, or fragments of furnace lining, can also be classified according to the types of the material. Most of them were identified because the surface was either vitrified or at least heated to a certain extent. Some even show a flowing pattern when the material was molten during iron production. I classify the furnace remains into four types (Table 5.4).

The first type furnace lining is tempered with some amount of straw-temper and corresponds to the material of first and second type of tuyères. The second type of furnace lining also belongs to the type with fine sand temper but without straw-temper. The third type uses coarse sand tempered clay as a raw material. The fourth type belongs to reused old or discarded casting molds. Data suggest normal fine sand-tempered clay was used about 5-6 times more than coarse-tempered clay in making furnace walls. In terms of the material, the coarse-tempered clay fragment is also very similar to the material of the third type of tuyère. The last type of furnace lining was made of used casting molds (e.g., H31y287; H31y288) as blocks of furnace walls. These materials include both hoe and plow molds, which might be used for repairing the inner surface of a furnace wall because the material itself can resist high temperature. When they were reused, a layer of coarse sand tempered clay could be pasted on the surface of a mold to increase the refractorability of the materials. So far, it is unclear whether the same furnaces used at the foundry were made of different materials or different types of furnaces used at the same time.

Table 5.4 Four types of furnace lining and three types of brick/burnt soil remain identified

	Furnace-linings		**Burnt-soil/bricks**
Type 1	Sand temper with some amount of straw-temper	Type 1	burnt soil with surface
Type 2	Fine sand tempered and without any straw-temper	Type 2	irregular burnt soil
Type 3	Coarse sand tempered	Type 3	brick of other materials
Type 4	Furnace reused casting molds	Type 4	Coarse sand tempered

In addition to the lining materials, a much larger quantity of burnt soil or brick material were found from these garbage pits. The majority might have been contacted with relatively high temperature but were not vitrified. For the purpose of records and quantification study, I also classify remains of this category into several types. The first type was burnt soil with more than one relatively flat surface, which might indicate the remains might have been used as furnace body or furnace bricks. The second type was completely irregular burnt soil. Remains belonging to this type would have been part of the furnace wall or any other features related to casting activities. The third type was the brick-shaped objects that were made of other types of materials such as stone. They all might have been part of the furnace wall or related remains[62]. The last type was coarse sand tempered clay fragments which are irregular and without signs of high-temperature burning. All these materials might have been combined to construct a furnace, a technical practice that was widely adopted during the Warring States period.

Since most of the materials were fragments, it is very difficult to derive reliable data to reconstruct the diameters of the (cupola) furnaces. Only four samples preserved enough arc length to calculate the diameter (Table 5.5). It is noticeable that the reconstructed radius seems to be relatively small: three figures show that the radius of the inner side might be just between 28~40 cm. The largest is just 79 cm (outer radius). This number is relatively small in comparison with other published data about reconstructed pig iron blast furnaces. Thus, I suspect that the reconstructed radius of furnaces might have been severely skewed by the fragmentation of debris. Because of the poor preservation of materials, furnace walls might not present enough data to allow a reliable reconstruction of furnace size.

[62] Some piece of burnt soil is in a brick shape. Furthermore, smaller size burnt soil might have been fragments of molds.

Table 5.5 Reconstructed diameter of furnace fragments

	Radius
H28y66	inner radius 35cm
H31y338	inner radius 28cm
H36y130	inner radius 40cm
T1(1)y20	outer radius 79cm

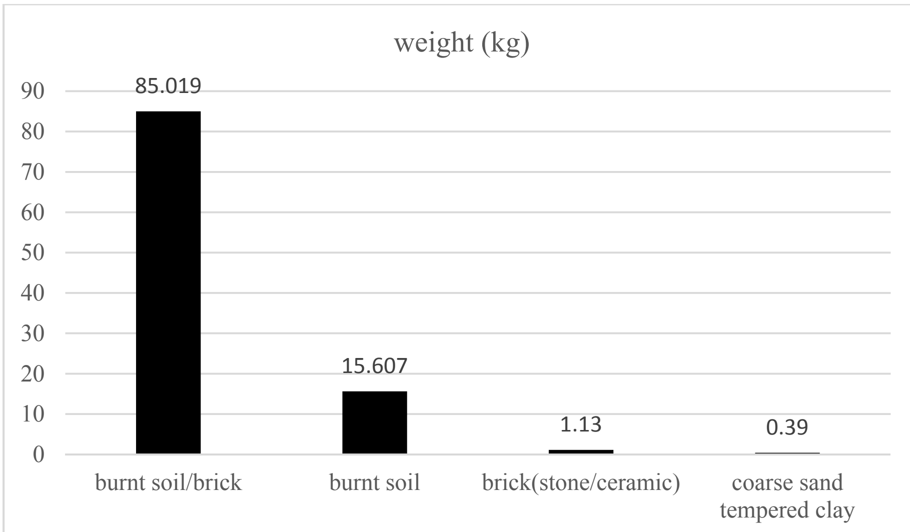


Figure 5.5 Total weight of four types of furnace body

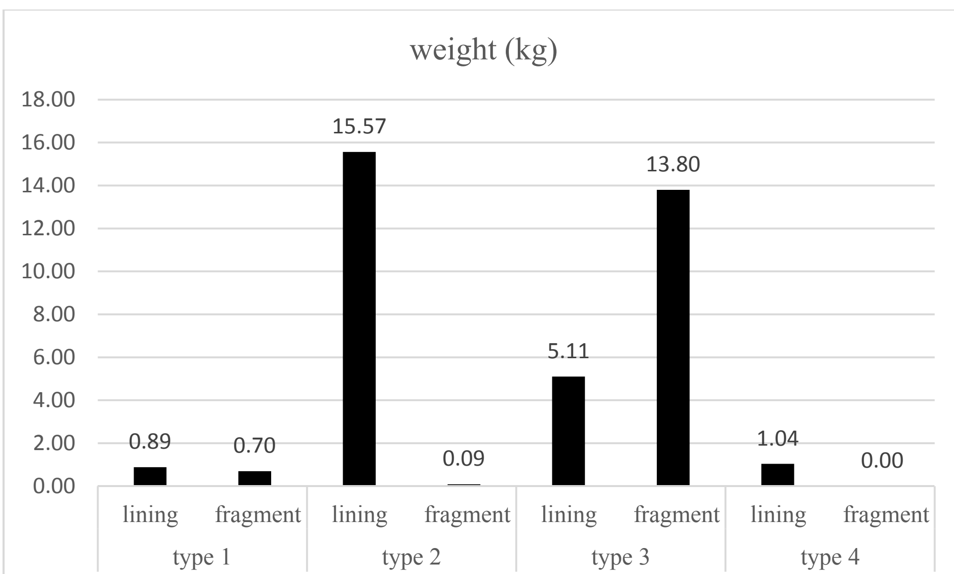


Figure 5.6 Total weights of four types of furnace lining

In Figure 5.5 and 5.6, I show the total weights of various types of furnace lining and furnace body in order to articulate the technological choices between different types of material. Coarse sand-tempered clay usually has higher refractory ability and resists higher temperature. Consequently, it seems to be more favorable to the selection of furnace raw material. About half of the material identified as furnace lining (with clear evidence of vitrified surface or contact with high temperature) was this type of raw materials versus straw-tempered or fine sand tempered clay. But for tuyères, just only about one-fourth were made of coarse-tempered sand. Also, this type of coarse sand-tempered material seems to be more frequently used for building the internal surface.

Given the fact that no complete furnace was found, and the result that all analyzed furnace-lining and slag (including coarse-sand tempered and clay body type) were related to the re-melting or production of cast iron, the investigation of the difference in the selection of material needs to take functions and workers' preference into full consideration. For tuyères, different types of pipes are very likely related to different ways they were used with the furnace or hearths, indicating differences in their functions. In terms of furnace materials, fine-sand clay and coarse-sand clay were both used as furnace lining and furnace body. Nonetheless, coarse-sand clay seems to be more favorable than the fine-sand material when it comes to the selection of furnace lining. Further analysis should try to identify and investigate the physical or thermal properties between these two categories, but these issues cannot be completely exploited here in the study. In Chapter 7, I will take a close look at the distribution of these remains to examine to what extent the discovery or distribution of these various types is related to the spatial organization of the foundry.

5.2.4 Iron pieces and iron tools

Alongside slag, tuyères, and furnace remains, a significant number of iron remains were identified. But most of the iron pieces were heavily corroded and small fragments. The original shape and their nature, in most cases, cannot be determined and are unidentifiable. These items might include at least several different categories: tools used in the foundry, tools that workers recycled from their neighborhood, iron ingots or raw materials for melting, and fragments of bear iron[63] pieces.

To better understand the natures of iron pieces found at the site, I classified iron pieces into two categories. The first category is iron tools or regular iron pieces. A piece of iron in this category is in good and recognizable shape, and we can therefore identify its original type or nature. The types that are known include at least an iron spade, a *ji* halberd, and one ring-pommel knife. According to the types these fragments represent, some of them (e.g., iron *ji* halberd) were not used directly by iron workers. The second category includes iron pieces in regular shape (e.g., a bar) as well as irregular iron pieces, but it is difficult to identify whether these pieces were originally iron tools, iron ingots, bear iron, or just manufacturing waste from the production process solely based on their appearance. Based on the classification, I recorded the weights of each category from each feature.

For this project, the study of iron pieces aims to determine if they were "artifacts" or "iron tools". But as I mentioned before, it is very difficult to determine as they were in a broken or corroded stage. In order to further clarify the nature of iron items from the iron foundry for the sake of archaeological studies, I collected iron samples (both iron tools and iron fragments) for metallurgical analysis. This study can further complement the study of slag and other remains to

[63] Bear iron refers to the cast iron inside the blast furnace that was cooled down and solidified because of mistakes in the manipulation of furnace. See Wagner 2008.

lay down the foundation for exploring issues such as raw resources, production techniques, and production organization. In section 5.4, the results of the metallurgical analysis will be discussed in a more detailed manner.

5.2.5 Casting molds, cores, and related artifacts

Casting molds can provide direct information about final products. I will first try to reconstruct the basic assemblage and count the minimum number of mold pieces represented by the fragments. In general, there are three major types of casting molds: hoe molds, plow molds, and chisel molds. Each category also includes certain sub-types. In addition, I will discuss the mold-making technique based on remains or traces of technical characteristics. This discussion can provide some essential information with which to identify and analyze the dimensions that are suitable for studying the issue of standardization in Chapter 7. The intra-site variation in mold size and metric measurements—which are closely relevant to the question of standardization—will also be discussed in Chapter 7.

Hoe molds

Hoes refer to a type of trapezoid-shaped and thin agricultural tool which could have been used to break ground soil (Figure 5.7). Starting from the Warring-States period, hoes had already become the major type of products manufactured by iron foundries in the Central Plains. Hoes could also be reused as a component of construction material for building furnace wall (Li 1994). However, iron hoes were rarely found in burials and other previously found residential remains. These types of products might have been frequently recycled as scrap iron after they were corroded and became no longer usable.

Table 5.6 Hoe fragments of different parts

	Upper Left	Upper Right	Upper L+R*	Lower Left	Lower Right	Lower L+R	E**	?	Minimum number of individuals Using the upper part
A	29	48	98	57	74	18	27	256	173
B	14	18	69	36	42	10	17	326	104

*L+R=left and right sides

**E=entire. If the molds were refitted, the number of all pieces were counted as 1 single piece.

Side A Side B

Figure 5.7 Hoe molds after refitting (Side A H3y1; Side B H3y18)

About 1400 pieces of hoe molds have been discovered from the Taicheng site. A complete set of hoe molds includes two parts, which I call as side A and B belows (Figure 5.7). Side A is the piece with a rectangular pouring gate and runner as well as a trapezoidal casting cavity. The shape of side B is the same as side A but without the trapezoidal cavity. Also, the pouring gate on side B is very short and in a funnel-shape. Based on the characteristics of surface and shape of pouring gate, side A and B pieces could be easily identified and differentiated.

In the assemblage, I identified a total of 780 pieces of side A mold, and 636 pieces of side B molds. After dividing them into different parts, I use the upper right part to calculate the minimum piece of complete molds represented by these fragments (Table 5.6). All side A and side B fragments represent at least 173 and 104 pieces of complete hoe molds. It is noteworthy that counts of each part of side B molds are all lower than the corresponding parts of the side A molds. Very likely side A and side B molds were not made in a pair at the same time. Since the casting cavity was craved on the surface of side A, this will increase the possibility of being broken when workers retrieve the final iron pieces after casting. As a result, workers needed to manufacture more pieces of side A molds than side B for replacement.

No tools or instruments related to the production of hoe molds have been found from the site. But its production may involve the following potential steps. First, the production of a hoe molds might start with a template model to form a trapezoidal-shaped plain mold[64]. Meanwhile, assembling markers, usually one ore three strokes of high-relief lines (see Chapter 7), were made on the type edge of a casting mold. Then mold markers used a knife of some sort to carve the pouring gate, runner and casting cavity. Theoretically, mold workers might also have some hoe templates in their hands to facilitate the carving of the iron cavity.

After making a draft on the mold surface, mold workers then started to remove clay and carve out the cavity. Workers needed to check whether the shape of draft lines matched certain standards. If not they would redo or remake the drafting lines on casting molds. Following the carving, molds could be dried for a couple of days for reassembling and firing in a kiln. Since each pair of mold might have been reused several times, molds would be repaired and prepared for the next casting. Because the cavity and runner were made by hand-carving, it is expected that variation in the dimension of the cavity would be considerable. The metric measurement of

[64] Another approach might have been using a knife to cut the original mold into halves.

the thickness and the size of runners—which I conduct in Chapter 7—should then be meaningful to evaluate the issue of mechanical standardization and understand the practice of mold making.

Plow molds and cores

Table 5.7 Counting of different portions of plow molds

	Large size	Small size
Upper left	23	20
Upper right	36	22
Upper left/right	5	3
Lower left	18	11
Lower right	21	10
Lower left/right	3	3
Minimum number of complete molds	36	22

Table 5.8 Counting of different portions of plow cores

	Large size	Small size
Upper left	109	49
Upper middle	84	38
Upper right	112	50
Reassembling marker	62	24
Tip-end	49	21
Minimum number of complete cores	112	50

The other major category is plow molds and cores. This type of iron products was added to the inventory of agricultural tools and produced on a massive scale during the Han period, but so far there is no clear evidence showing the large-scale manufacture of iron plows in the precedent Warring States period. A complete set of reassembled plow molds includes two pieces of external molds and one piece of core[65] between the two pieces of casting molds to create the casting cavity (Figure 5.8). A chaplet or spacer was made on the both sides of a core in order to stable the core in between two pieces of molds. The final products were a tongue-shaped large piece of iron tool which can be mounted on its wooden part. According to Liu (2010), during the Han period there were three types of iron plows, and this type of plow excavated from Taicheng represented an earlier version. Later on this type of plow was replaced by a V-shaped plowshre for which only the tip or edge part was cast in iron.

a. Small size plow mold b. Small size plow core

Figure 5.8 Plow mold and core (a H31y151 b H31y234)

[65] Following the bronze-casting technique, materials for making molds and cores were different from those for hoe molds. Plow molds used materials with very coarse and large-size temper, while plow cores were made of fine clay material. For a detailed technical discussion see (Tan and Wang 1999).

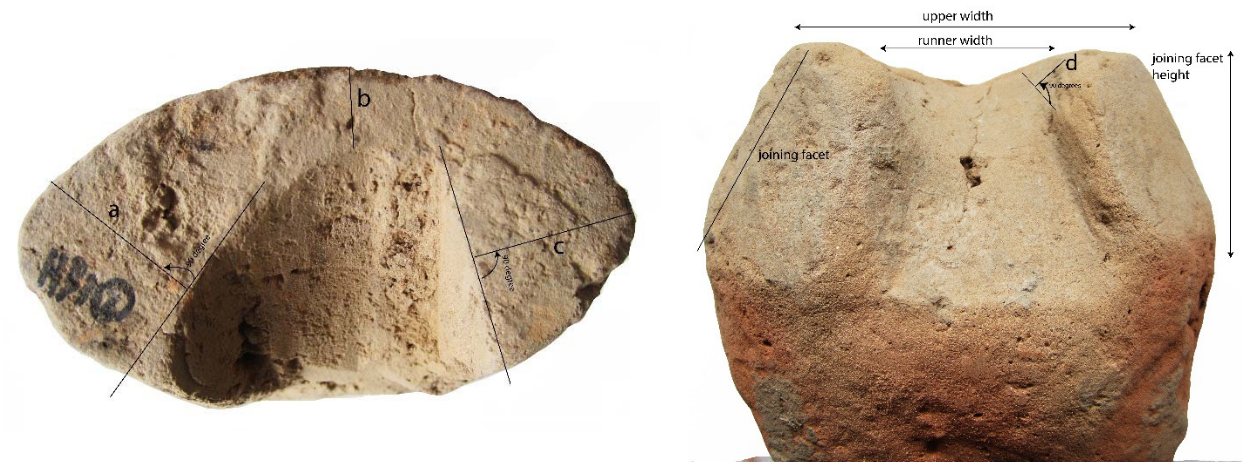


Figure 5.9 Illustration of metric measurement of plow cores

Plow molds usually are larger and thicker in size in comparison with hoe molds (Figure 5.8, 5.10, 5.11; Table 5.9, 5.10). But plow products present a wider range in terms of their size, and the study of standardization must fully take the issue of size variation into consideration. The size of molds can be classified into at least two categories: the first type is relatively larger with 30 cm long and 20 cm wide, while small-sized plows usually are 20 cm long and 15 cm wide. The small-size plows might have been pulled by other types of animals or mounted on a different type of plow. In order to better demonstrate the size variations between these two types, I plotted the descriptive statistic data on box-plots (Figure 5.10, 5.11). Since for each group there are certain outliers based on the size and measurement of dimensions, I suspect that, in the two categories of plows available on the market, their sizes of each category might not be entirely standardized.

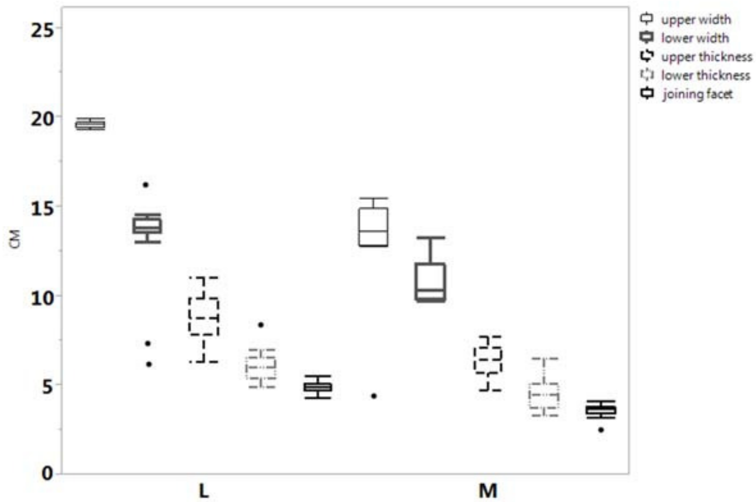


Figure 5.10 Comparison of metric measurements of different types of plow molds
(L=large; M=small)

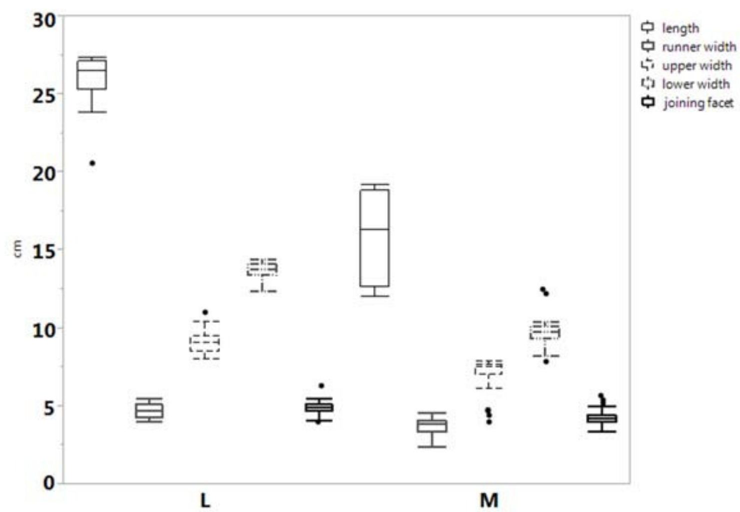


Figure 5.11 Comparison of metric measurements of different types of plow cores
(L=large; M=small)

According to fragments, about 600 pieces of plow molds were found. After classifying these based on the parts or portions that are present, these fragments represent at least 36 pieces of complete large plow molds and 22 pieces of small complete plow molds (Table 5.7, 5.8). Large size molds usually are fragile and easy to be broken; so far none of the refitted large plow molds are entirely complete.

Because the plow core cannot be easily retrieved after casting and needed to be discarded, it is not surprising to see the minimum numbers of cores are much higher than those of plow molds. At least 800 pieces of plow cores were identified. All these fragments represent at least 112 pieces of large plow cores and 50 pieces of small plow cores. Furthermore, after each episode of casting, each core needs to be damaged and broken into pieces in order to take away the final product, the original number of plow cores must outnumber plow molds. Due to this fact, it is not surprisingly to find the minimal number of cores is about two times the number of plow molds. Also, since each set of plow molds requires two pieces to reassemble, each set of molds might have been reused more than four times; otherwise the counts of core fragments would not have outnumbered those of molds.

Because of its relatively complicated dimensions, the production of plow molds might involve steps or produces different from those of hoe molds. In order to make the large casting cavity, mold makers might start with making a model core such as the one shown in Figure 5.13 as a template[66] with a rectangular-shaped box. To make a plow core, an "opposite" model with a cavity in the shape of a core was necessary. Workers might just use a model similar to a casting mold to replicate the steps mentioned above to manufacture a core. On the plow core models, a small cavity in various shapes was made in order to make replicate the spacers on the surface, which are used to strengthen the reassembling of a core and molds and create the space for the running of cast iron liquid. As I will explain in Chapter 7, these types of reassembling signs include five different types, indicating plow molds and cores were also made by groups of

[66] The two internal facets of molds are not entirely identical, however, the one that connects the face of core with the casting channels would have a more deeply curved cavity, while the other side would have a relatively flat surface to connect with the core. In other words, workers might need two different models to produce a set of casting molds.

workers with different practices. The last step of making a core involves the cutting of a pouring gate, which had to be made by hand individually on each piece of core. Since plow molds are much large in size than hoe molds, reassembling signs appear not only on the top but also on the bottom edge of the casting molds to facilitate the reassembling.

Table 5.9 Metric measurements of plow molds

		upper width	lower width	upper thickness	lower thickness	joining facet
Large	N	8	17	34	25	31
	Mean	19.59	13.17	8.82	6.00	4.90
	Std Dev	0.19	2.51	1.10	0.79	0.30
	CV	*0.96*	*19.05*	*12.45*	*13.14*	*6.05*
Small	N	10	10	30	14	25
	Mean	12.99	10.76	6.42	4.54	3.61
	Std Dev	3.19	1.28	0.86	0.90	0.33
	CV	*24.54*	*11.91*	*13.35*	*19.78*	*9.26*

Table 5.10 Metric measurements of plow cores

		length	runner width	upper width	lower width	A	B	C	D
Large	N	11	25	28	26	85	98	73	55
	Mean	25.72	4.66	9.06	13.67	3.07	2.21	3.10	1.77
	Std Dev	1.99	0.45	0.67	0.51	0.72	0.72	0.66	0.32
	CV	*7.75*	*9.71*	*7.38*	*3.72*	*23.58*	*32.40*	*21.30*	*17.79*
Small	N	5	30	26	26	41	40	39	35
	Mean	15.86	3.72	7.00	9.75	2.08	1.13	2.28	1.82
	Std Dev	3.15	0.56	1.16	1.02	0.46	0.55	0.43	0.56
	CV	*19.88*	*14.93*	*16.58*	*10.44*	*22.20*	*48.60*	*18.78*	*30.99*

Because of this production procedure, not surprisingly the shape of the cores (counting by the widest place) appears to be highly standardized with very low CV values. Furthermore, the CV values of small cores appears to be higher than those of large ones, indicating the smaller size of plow cores might include a wider range of variety. I also recorded four metric measurements to describe the shape of runners, using the code A, B, C, and D (see Figure 5.9).

Perhaps due to the fact that the cutting was done by hand, the four dimensions demonstrate much larger CV value than the shape or profile of cores.

Although molds and cores were produced by separate models and thus generally were highly standardized, the ways and practices in making runners even for the same type of cores seem to be slightly different. Since these dimensions are not directly related to their function, mold or core markers were able to create the runners in their own custom manner. In terms of the difference in the CV values between large and small size cores, however, they might be attributed to different factors. I suggest that the small plow molds and cores might include several sub-categories that are slightly different in terms of their sizes. Or the small category of plow molds and cores was manufactured by groups of workers with less control in terms of their skills.

Chisels and other types of molds

The third type of products was the chisel (Figure 5.12). Each set of molds in the assemblage includes three pieces components: the side of mold with the casting cavity, the side of mold that is relatively flat and without any casting cavity, and a core. The casting molds are in a rectangular shape and designed to cast two rectangular-shaped chisels each time. The numbers of chisel mold fragments were significantly lower than those of the other two types of molds. All fragments represent about 8 pieces of individual molds and 53 pieces of cores (Table 5.11). It seems that chisels might have been cast occasionally and not the type of routine product in the inventory. In terms of material, chisel molds and cores are very different hoe and plow molds based on the observation of visual characteristics. Furthermore, the texture of the core is different from a plow core in the material; chisel core appears to be more compact, solid, and fired at a relatively high temperature. The differences in the selection of material corresponding to different type of molds and cores clear demonstrate a systematic labor-division in the preparation and manufacture processes of casting molds between the three categories of molds.

Figure 5.12 Chisel mold and core

Table 5.11 Counting of core and mold fragments of chisels

chisel	cores	mold
Minimum number of complete pieces	53	8

Besides molds for casting final products, there are several cases showing used or non-used molds was reused for other types of purposes. H31y214 (Figure 5.14), for instance, was about half of a hoe mold but was carved with the cavity of an unknown shape of object. Workers might have reused this piece of hoe mold to practice the casting or making of types of products other than agricultural tools. Since this evidence is too sporadic in the assemblage of excavated material, at this stage it may not be safe to conclude that the iron foundry also engaged in the mass-scale production of casting molds.

Figure 5.13 H33y79. A model that might have been used to make a plow core

Figure 5.14 H31y214. A piece of hoe mold that was reused to cast another object

After the introduction of all these categories and variations of manufacturing waste, several aspects are particularly relevant to the investigation of the *chaîne opératoire* and organization of cast iron production. I would like to highlight these aspects and articular their implications before I move forward to the analysis of slag and iron pieces.

First, the iron foundry might not just perform casting. The inventory indeed includes evidence related to mold production or the procedure of making the casting cavity in molds, even though the numbers of this type of remains are hitherto limited in comparison with other types of manufacturing waste in the assemblage.

Second, according to the variations in tuyères and furnace lining identified, the iron foundry might also conduct smithing or refining that requires using the types or forms of furnaces and tuyères different from those of remelting. Again, melting might not be the only function or production procedure performed at the site.

Third, casting molds show that the iron foundry specialized in casting two types of agricultural tools: hoes and plows. Under each category, the iron foundry also produced versions of different sizes according to customers' need. Although the products reflected by molds appear to be highly standardized, the same category of molds or cores was, in fact, made by several groups of workers or mold makers. Also, the metric measurements and ways of cutting runners already demonstrate the variation in terms of workers' preference and customers. In Chapter 7, I will continue to investigate issues related to workers' mechanical and intentional standardization. Furthermore, I will address whether molds with different markers or metric characteristics demonstrate certain distribution patterns in the intra-site analysis.

5.3 Metallurgical Analyses of Slag Remains

Most slag from the foundry was glassy remains with certain porosity structure and between white, grey and greenish in color, which are typical characteristics of blast furnace or cupola furnace slag. To further investigate iron techniques, I have collected 78 samples from the three categories to subject to metallurgical analysis (Table 5.12). Then 28 samples were selected for SEM-EDS analysis. Three to four areas of each sample were scanned to collect data of chemical compositions in order to calculate average compositions (Appendix B: Table B.1, B.3, B.4). In addition, I collected chemical compositions of iron globules showing P-Fe eutectic structure (Appendix B: Table B.2).

According to the microstructure and chemical compositions (Appendix B: Table B.1), the majority of slag selected for analysis belonged to the Si-Ca-Al glassy slag system, typically representing the chemical compositoins of copular furnace (or blast furnace) slag. In addition, there are three pieces of slag analyzed that contain relatively high iron and were not generated in a highly reducing environment; they might have belonged to refining pig iron slag production. In addition, seven pieces of slag/furnace lining slag—remains that might belong to incompletely molten furnace lining—were identified. The microstructure and chemical composition will also be discussed below.

Table 5.12 Identification result of analyzed slag samples

cupola furnace slag (iron melting slag)	furnace lining/slag	other	*total analyzed*	*SEM analyzed*
68	7	3	78	28

5.3.1 Si-Ca glassy cupola slag

The majority in analyzed samples belongs to this category. The matrix is very glassy with a few iron globules and Si-Ca crystalline structures. No incomplete molten iron ores and fayalite-wüstite constituents have been found in any of these slag pieces. Inclusions usually include charcoal and large gray cast iron pieces. In the inclusions of large-sized iron piece droplets inclusions, 100% are cast iron. In three SEM analyzed samples (Appendix B: Table B.1), un-molten lime ($CaO2$) was found (Figure 5.15). Given the variation in the cooling rate, crystalline structures in various sizes and amounts are commonly found in the microstructure. According to the chemical compositions, the crystalline minerals in iron slag usually consist primarily of Si and Ca, and in general belong to wollastonite. Un-molten quartz particles (Figure 5.16) were also relatively common in four SEM samples analyzed. In addition, the remains of hammer scale were found embedded in at least one sample (71155:3) (Figure 5.17). Quartz particles might have been derived from the material of furnace lining, but they could also have been added intentionally alongside hammer scale as a flux, which is a type of normal additive for cupola melting process that involved recycling scrap iron.

In terms of the chemical compositions, this type of slag included about 30~50% Si, 20~50% Ca, and 8~10% Al (Figure 5.19). Iron is constantly low in the chemical compositions, indicating workers did professionally control the reducing environment and the slag separation for the high yield of iron. Except Si, Al, and Ca, other elements are low in the compositions. In most area-scanning data, the wt% of Na, Mg, Mn, and Ti are generally lower than 5%. Since calcium is relatively high with very low percentage of magnesium, limestone should have been used as fluxes to reduce the melting temperature and clean up ashes or impurities, a conclusion indisputably supported by the identification of incompletely molten lime mineral in slag.

In cupola furnace or blast furnace slag, the management of acidity is related to the adding of flux, material of furnace lining, and chemical elements in the raw material. In slag, Mg and Ca are considered as basic elements, while Si belongs to an acid mineral. The nature of Al might serve as both acid and basic elements, depending on the acidity of slag. Thus, the basicity of slag can be calculated by the formula:

basicity=(wt%CaO+MgO)/wt%SiO2

According to this formula, the basicity of slag from Taicheng is about 0.7 in average based on data listed in Appendix B: Table B.1. In other words, the majority of scanned samples belongs to acid slag or low basic slag. In Table 5.13, I also list the comparative basicity calculated based on published data from sites that are related to ancient iron production during the Han period. The preliminary comparison seems to suggest that the basicity of slag from iron smelting sites is relatively lower than that from iron melting sites. For instance, the basicity of Wanchenggang 望城岗 is much lower than that of Dongpingling 东平陵 and Taicheng. In modern iron industry, high basicity is often related to desulphurization when coke was used as fuel. As basic slag can better remove sulfur, modern blast furnace slag tend to be basic (above 1.3) in order to purify phosphorus in pig iron. But in the Han period, charcoal was the major source of fuel in the iron industry, and pig iron, in general, should be free of sulfur; the higher basicity of slag from melting sites should not be related to the purification of phosphorus. Future studies should try to collect more data to test whether the average basicity of slag is relevant to the function of an iron production site.

Table 5.13 Comparison of slag basicity from four Han iron production sites

Site	Nature	Basicity
Taicheng	Melting	0.7
Linzi (Du et al. 2011)	Smelting and melting	0.5
Wanchenggang (Chen et al. 2011)	Smelting and melting	0.22
Dongpinglin (Zhou 2014)	Melting?	0.61

The composition of P, in general, is high in slag as well as in iron globules. Also, after etching, iron globules often show a two-phase structure: the high P P-Fe eutectic structure and lower P ferrite or pearlite structure. Micrographically, the former usually seems to stand above the surface, while the later seems relatively sunken (Figure 5.18). Appendix B: Table B.2 lists the chemical composition of iron globules analyzed by SEM-EDS. In my collected data, the P-Fe eutectic structure in some samples contained P as high as 18~20%.

Phosphorus is an element notorious in impacting the quality of iron and steel by increasing the brittleness. In modern industry, iron ore with more than 1% (mass %) of P will be considered as lower grade because of the cost of dephosphorization associated. According to Zhang's (2014) study on slag from the Han iron production site (melting) at Dongpingling, she also identified globules with high P percentage ranges between 12.2~17.3% in the P-Fe eutectic structure. As Zhang pointed out (ibid:67), the high P in iron globules might be relate to several factors, including the P content in the raw materials (i.e., scrap iron), the basicity of slag, and the cooling rate of slag during the melting processes. The discovery of high P composition in iron globules supports my argument that the majority of slag should be associated with cupola furnace slag manufactured by the recycling of scrap iron.

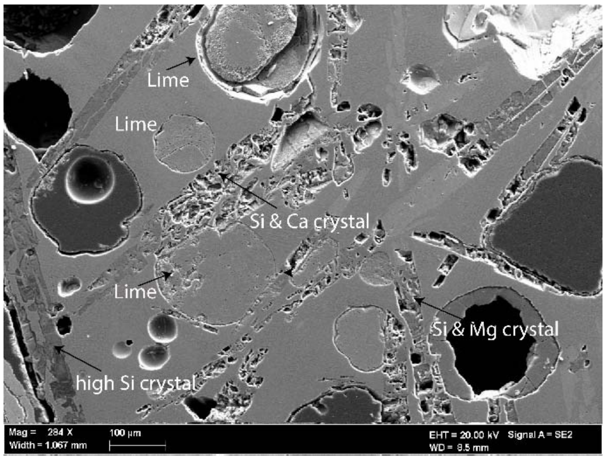


Figure 5.15 71205 secondary SEM image

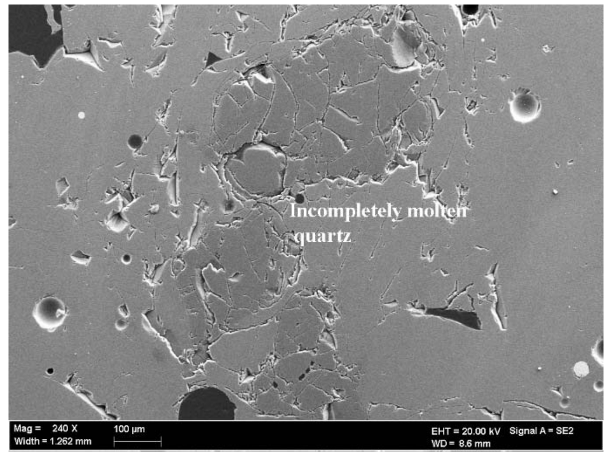


Figure 5.16 71197 secondary SEM image

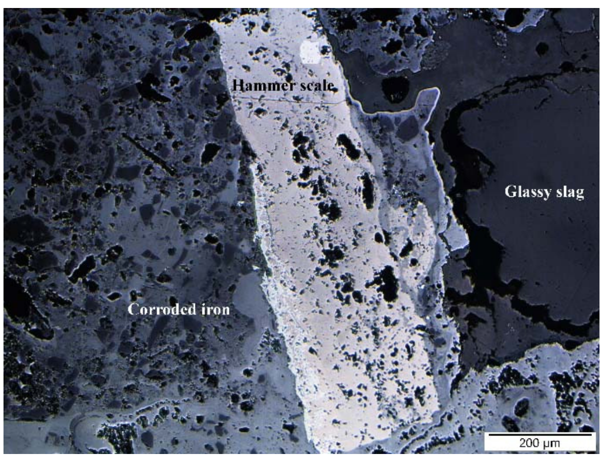


Figure 5.17 71155:3 microphotograph shows a piece of hammer scale embedded in a glassy slag

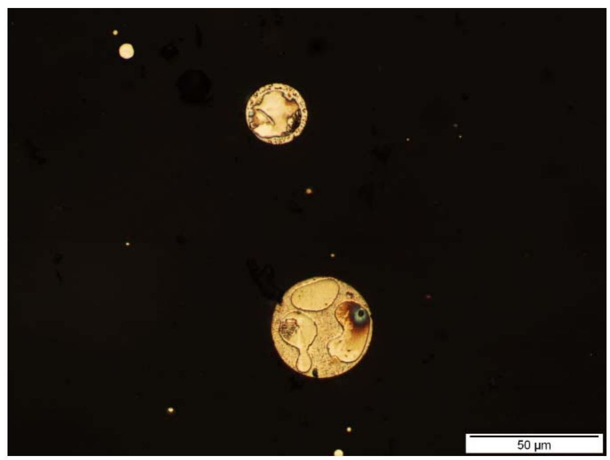


Figure 5.18 71183 microphotograph of cupola furnace slag and iron prills with P-Fe eutectic structure

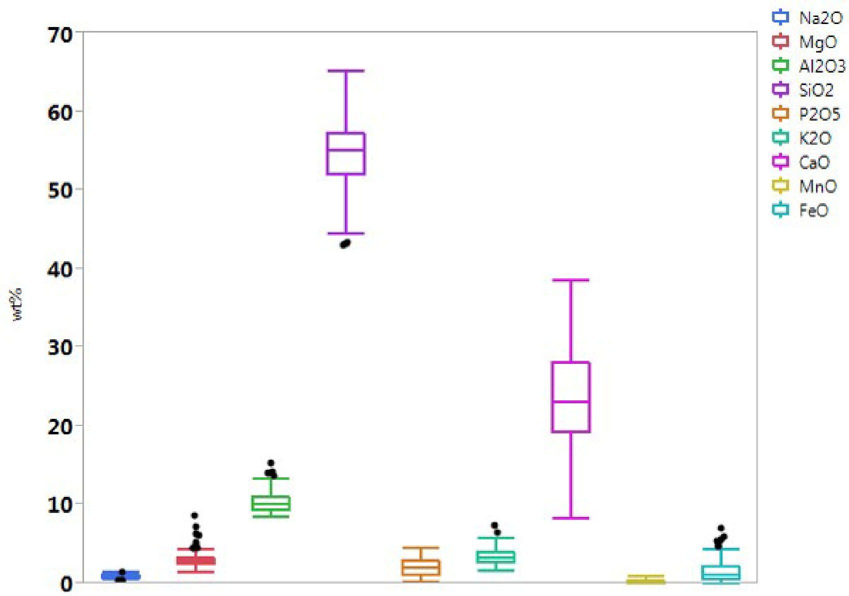


Figure 5.19 Box-plots of all area-scanned samples (glassy cupola furnace slag)

5.3.2 Fe-rich glassy slag (Refined pig iron slag)

The second type of slags only includes three samples. 71139[67] (Figure 5.20:2) belonged to the special type of slag identified during the first step of classification because of its mall and round shape. Its non-glassy and vitrified surface is also different from other slag pieces that were commonly found. In addition, one side of its surface shows an overlap structure or layer of strip-like molten slag. In contrast, 71147:2 (Figure 5.20:1) looks similar to other slag-charcoal mixed slag pieces. During the first step of classification, this sample was identified as type 2 slag. 71192 (Figure 5.21) also shows surface texture and visual characteristics that are different from common cupola slag, and is identified as one typical example of special slag.

[67] For the convenience of recording, all samples were given a lab number after they were samples, and the coding system follows the rule in the Peking University metallurgy lab.

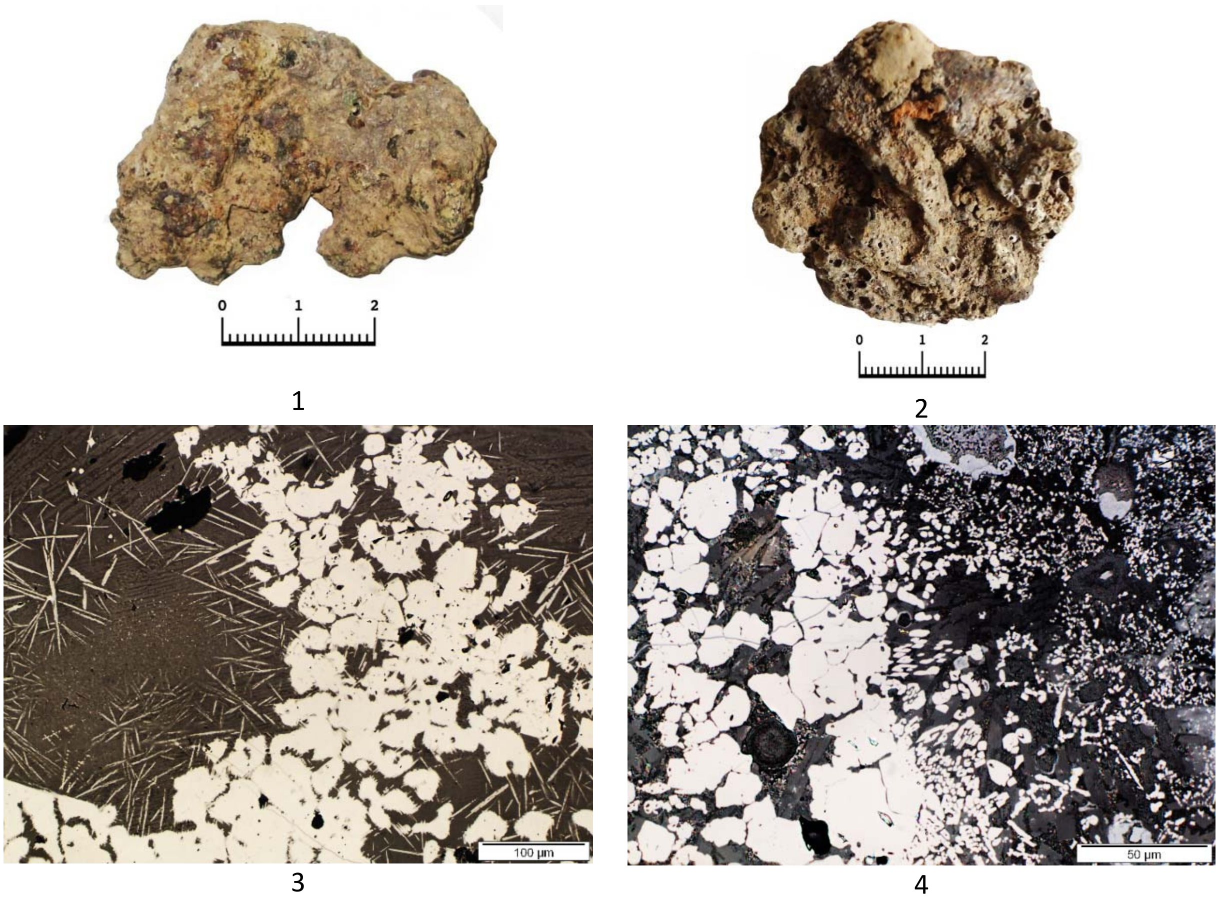


Figure 5.20 Microphotographs of refined pig iron slag (1, 3: 71147:2; 2, 4: 71139)

In the microstructure of 71139, lots of iron oxide in the form of magnetite is distributed and aggregates in a glassy structure matrix (Figure 5.20:4) and aggregates together. In the glassy matrix, fayalite and high Ca minerals were also identified. In 71147:2, iron oxide in the form of magnetite and wüstite were also identified mixed with the glassy matrix. The iron oxide and wüstite distributed at the edge or surface of a slag, which contains lots of quartz inclusions and might belong to incompletely molten furnace linings. In addition, fayalite was also occasionally found in the slag, but is not dominated in the structure.

The structure of 71291 contains large-size iron globules mixed with glassy slag (Figure 5.21). The glassy matrix is also relatively high in Ca, and chemically similar to other cupola furnace slag from the site. Given the form and structure of iron globules that were found, the nature of this piece might have been slightly different; it could be either a refined pig iron slag or a cast iron slag containing high percentage of iron due to an accident operation. In terms of chemical composition and the amount of iron oxides identified, 71139 and 71147:2 should have been generated by a relatively strong oxidizing environment, or refined pig iron production[68]. During the refining process, most of the iron was oxidized and entered into either to slag or was picked up by SI. Therefore, refined pig iron slag usually is relatively high in iron[69]. But for 71292, the chemical compositions are more similar to cupola furnace slag but with a high wt% of Fe. This pattern might have been generated by rapidly stirring slag when it was flowing out or by the processing of refined pig iron production.

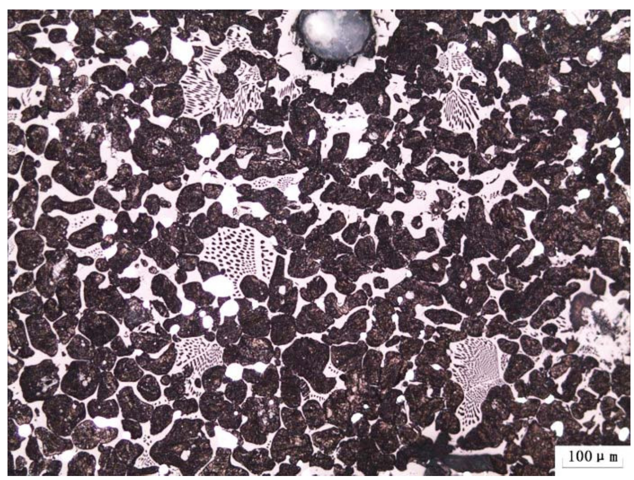


Figure 5.21 71291 and its photomicrograph. The microphotograph was taken after etching

5.3.3 Furnace-lining slag

[68] Even though smithing slag was created in an oxidizing environment, the study of smithing cake of bloomery iron shows that its typical structure should be glassy structure with fayalite and wüstite (Gordon 1997) instead of magnetite and fayalite because smithing could be conducted in a less oxidizing environment.

[69] For this reason, the iron-yielding of refined pig iron could only reach 50~70% even during the 19th Europe from the original pig iron (Dillmann and Bellot-Gurlet 2014).

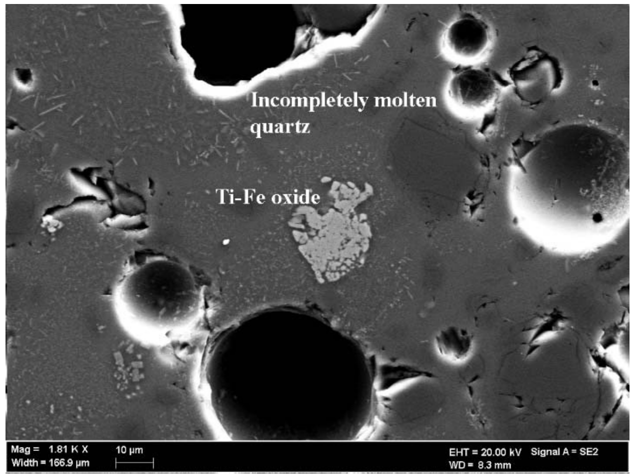


Figure 5.22 Secondary SEM image of 71162:1
The feature in the center is Ti-Fe oxide. Incompletely molten quartz, probably derived from furnace lining, was adjacent to the Ti oxide

Among all identified samples, seven pieces belonged to the type of furnace-lining slag, namely the semi-molten or vitrified parts of furnace lining. A total of four samples have been selected and subjected to SEM analyses. This type of slag usually exhibits gray or dark greenish color but with a very low degree of vitrification. Its structure is typically porous with lots of bubbles and cavities as well as un-molten quartz, the latter probably coming from furnace lining. In all these samples, extremely few iron globules were found in the microstructure. Incomplete molten Ti or Ti-Fe oxide was also found in the matrix (e.g., 71161:1, Figure 5.22). This mineral might also derive from the materials used for building furnace lining.

In terms of the chemical compositions, the remains show higher percentage in the wt% Si and wt% Al. Wt% Fe is also relatively higher, but wt% Ca, in general, is very low (Appendix B: Table B.4), indicating that the remains did not come from the section directly contacting with the fuels or charges. Instead, this type of slag might come from the process of heat-exchange between furnace lining and the volatile elements (Zhang 2014:58). In these samples, wt% K also appears to be higher than the value of glassy slags, indicating that the wt% K in furnace lining might have been the major contributor to the element in furnace lining slag.

Summary

The metallurgical analysis of slag helps to clarify the nature of manufacturing waste regarding serveral aspects. First, the microstructure and chemical compositions support that the majority of slag is related to cupola furnace slag. As sands, flux, and hammer scale were added to form slags to get rid of impurities in recycled scrap iron, the major form of iron resource.

Second, the discovery of incompletely molten lime in analyzed samples and relatively high content of Ca in glassy matrix undoubtedly shows that pure limestone was used as flux to form slag during the melting process. In addition, the percentage of Fe is also consistantly as low as 2%. In terms of other elements, the range of variation of Na, Mg, and Mn is relatively limited. Since the chemical composition of slag is quite homogenous with very low fluctuation, the ratio between scrap iron, fluxes (sand and lime) and fuel might have been well controlled in order to sufficiently separate the slag and iron. Without a careful management of iron-slag separation and the reducing environment, the content of Fe in slag would easily become much higher than this low range (Chen 2008).

Third, the metallurgical study demonstrates that the iron foundry also engaged in some kinds of pig iron refining processes. Given the chemical compositions and microstructure, at least two samples (71139 and 71147:2) should be clearly related to pig iron refining processes. Although the shape of hearths[70] and the method of refining was not addresssed through excavation, it is undoubtedly the case that iron workers were knowledgable in refining techniques and were able to produce the type of raw material that is suitable for hammering and

[70] Of particular interest, the chemical compositions of these refining slag samples correspond to the slag/furnace lining.

forging. Therefore, the material used to construct refining hearths might not be very different from that used for cupola furnace. Nonetheless, given the small numbers of samples found, the production of refined pig iron might have been occasionally conducted to complement the production of agricultural tools on a very small scale. In short, even though the iron foundry seems to be small in size, this metallurgical evidence shows that workers achieved a high level of proficiency in the skills of iron melting. The site also provided refined pig iron raw material, indicating the final products were not limited to the three types of agricultural tools.

5.4 Iron Remains and Metallurgical Analysis

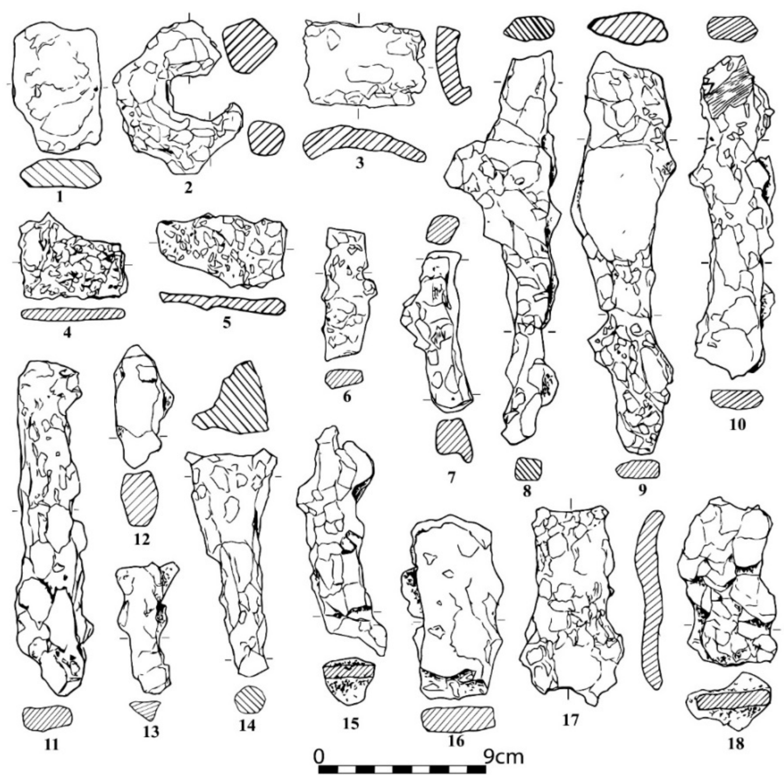


Figure 5.23 Drawings of iron fragments sampled for metallurgical analysis

1.H31Y271(71124) 2.H31Y245(71108) 3.H33Y84(71168) 4.H34①Y88(71266) 5. H36Y123(71203)
6.H33Y86(1)(71174) 7.H31①Y261(71119) 8.H31①Y266(71165) 9.H31Y274(71148) 10.H33Y81(71170)
11.H28Y61(71290) 12.H5Y5(71274) 13.H33Y85(71171) 14.H31①Y258(71117) 15.H12Y2(71186)
16.H31①Y250(71126) 17.H31Y277(1)(71150) 18.H12Y3(71187)

Since the majority of iron remains were fragments of irregular shape, for the metallurgical analysis I particularly focus on sampling the second category (i.e., iron pieces with or without regular shape that are difficult to identify). From all excavated features, a total of 106 pieces have been collected. I will first introduce the results metallurgical analysis, which will then be synthesized with the shape of iron pieces to investigate their natures further.

The table below (Table 5.14) is the result of identification of all samples and the numbers of each technical category. In the discussion below, I will specifically introduce the details of identification and microstructure of 15 samples. They are identified as refined pig iron products and decarburized steel/malleable iron objects, which are very likely iron products or tools with specific functions. In terms of samples that are identified as cast iron, gray cast iron, and mottled cast iron—which are much outnumbered—their results will be just briefly discussed because these samples are difficult to confirm whether they are iron tools, products, or just manufacturing waste.

Table 5.14 Result of metallurgical identification of iron pieces

	Cast iron	Decarbulized steel/malleable iron	Refined pig iron	Wrought iron	Completely corroded	Total
regular shape	25	6	5	11	9	56
irregular shape	32	3	0	6	10	50

5.4.1 Refined pig iron products

Refined pig iron was one major method to produce steel in the Han period. Iron remains correspond to the study of slag that Taicheng might not only produce but also may have obtained refined pig iron as a type of raw material. Four samples with dense and large amount of SI that were highly deformed and elongated should belong to refined pig iron[71] objects made by an indirect reduction process. In Appendix B (Table B.5), I list the SEM results of SI analyzed. In general, their compositions are low in Al, Mg, K (below 10%), but high in Fe, Si, P, and Ca. The majority of SI is glassy, and few of them include iron-oxide or non-metallic compounds including P, Ca, and Si. In addition, the degree of deformation shows a wide range of variety. These characteristics match the standard of refined pig iron SI mentioned above.

These samples also present various ways of forging or hammering. In sample 71117 (Appendix A:1,2), the microstructure is primarily ferrite with large amounts of SI, in which iron oxide was found. The entire structure (including the metallic matrix, SI, and high-P eutectic bands) was deformed in a U-shape, indicating the iron object was made by blending and folding a piece of wrought iron. In particular, the ferrite grain sizes and the direction of deformation are different in the outer part of the sample, suggesting that this single piece was made by piling and hammering several pieces of bloom, a practice that is different from other refined pig iron.

For the samples that were not heavily processed, 71119 (Appendix A:5) is a case with small amounts of highly deformed and elongated SI were found alongside the so-called "ghost structure", or the P-Fe eutectic structure that make certain parts of the component hard to etch. 71119 and another sample, 71121 (Appendix A:3) did not show how the sample has been worked or deformed. It is of interest to note that the microstructure of 71126 (Appendix A:4) might have been made by piling two pieces of wrought iron together and represents a layered

[71] Although some scholars prefer to translate *chaogang* to puddling iron instead of refined pig iron here, I suggest the later term is a better translation and causes less misunderstanding. In the modern iron industry, puddling iron or steel refers to the products produced by a blast furnace fueled by coke. The SI of such type of products usually are high in the composition of Sulphur. But in this case, charcoal, instead of coke, was the major type of fuel, which leads to a different pattern of chemical compositions in slag.

structure: the upper layer in the photomicrography consists of uniformed and small-sized ferrite, while the size of ferrite in the lower layer is much larger. Also, SI were distributed in two parallel lines and were highly elongated in the working direction. These four samples match the criteria of refined pig iron, and thus should not be manufacturing waste or any accidental product.

5.4.2 Decarburized steel and malleable iron

In addition, there are 7 samples belonging to decarburized steels or iron products. Decarburized steel refers to cast iron products that are heated or annealed in a solid stage inside a furnace for a certain period of time in order to decarburize the products. The final products would be steel with various degree of carbon content (Han and Ke 2007:604). For instance, 71108 (Appendix A:10) shows the microstructure of pearlitic ferrite with widmanstätten structures. In addition, the carbon content is unequal and higher on the surface than the center. This object is a piece of decarburized steel, and its surface was carburized and tempered by annealing. Similarly, in the core of sample 71174 (Appendix A:7), the structure is eutectoid-steel consisting primarily of pearlite, but there is cementite adjacent to the surface, indicating the object was decarburized first and surface-carburized again.

But not every decarburized sample shows the treatment of annealing. The structure of 71186 (Appendix A:9) is primarily ferrite, and is a product that is completely decarburized into wrought iron. Sample 71290 was a hypereutectoid steel (pearlitic ferrite) with sporadically appearing widmanstätten structures (Appendix A:8). Also, sphere-graphite was found in this sample, which is also an indicator of incomplete decarburization. 71144:1 (Appendix A:11) is a relatively special sample as its surface shows the structure of decarburized steel while the core still maintains the original hypereutectic cast iron structure. This might be either an incomplete or a failed decarburized product. Since these products rarely have SI, while sphere-graphite and shrinkage holes were quite commonly found, they should be decarburized steel products but with different types or manners of annealing treatment.

Malleable iron is another method to improve the mechanical property of cast iron through annealing. When cast iron objects were annealed at 900℃ or higher for a relatively long period, the cementite will decompose into graphite. Especially when the annealing process is sufficient, the product will change to pure ferrite with spherical-shaped nodules graphite. A total of two malleable iron pieces were found in this study (Appendix A:13, 14). 71153:3 was completely decarburized to ferrite and still maintained a spheroidal graphite structure. Sample 71274 shows a transitional structure with one side as malleable iron while the other side is hypereutectoid steel. These two samples might originally belong to some sorts of iron tools.

5.4.3 White and gray cast iron

Not surprisingly, the majority of samples in the study are either white or gray cast iron. The former includes at least 33 samples. Additionally, there are 4 corroded samples that preserve a small portion of pearlite and ledeburite (Fe3C), which should also be white cast iron. In these white cast iron samples, most of them are hyproeutectic cast iron, such as 71264 (Appendix A:17). There are also 2 samples with unequal carbon content including both hyproeutectic and eutectic iron, such as the sample 71232 (Appendix A:16). Five samples were identified as gray cast iron[72], which shows typical flake graphite, such as 71106 (Appendix A:18). These gray cast iron samples could be directly cast objects, decarburized objects, or even bear iron. This provides

[72] The formation of grey cast iron depends on the chemical compositions (Si primarily) and the speed of solidification. Bear iron inside a blast furnace would have cooled down at a relatively low rate as the furnace could maintain the heat and temperature inside even when the blasting stopped.

an environment for austenite grains to precipitate into graphites. Besides, there are 19 samples that were identified as mottled (cast) iron or "*makoutie* 麻口铁", which is a transition or combination of grey and white cast iron in a casting and include unevenly distributed graphite flakes. In some cases, mottled iron is not necessarily a desirable products (Bramfitt and Benscoter 2001:18), which means it was produced accidentally and very likely just manufacturing waste. Therefore, samples identified as cast iron (including both white and grey cast iron) can be either iron products, raw materials for remelting, or manufacturing waste if their shapes are irregular.

5.4.4 Other types of iron products

Although certain numbers of iron samples in this study were heavily corroded, the microstructure of some of them still is identifiable because of the selectivity of the corrosion process of iron (Rong 2012). For instance, in sample 71148, its metallic body was almost completely corroded; but the remains of SI and the trace of oxides (Appendix A:19) shows that it is either a piece of wrought iron. In this study, there are 16 corroded samples identified as "wrought iron", which could have been products of bloomery iron[73], malleable iron, or refined pig iron. According to their preservation, these samples can be further subdivided into two groups. The first group, including six samples, still preserves a small area of metallic body, which basically is ferrite but without any SI preserved in the area of metallic body. The second group includes ten samples that are almost completely corroded, but the traces or remains of ferrite and pearlite still are identifiable, such as in 71150:1 and 71165 (Appendix A:21, 22).

[73] Although SI cannot be found in samples belonging to these two categories, the corrosion in wrought and bloomery iron usually starts along SI. Thus, we cannot further identify the techniques of these samples only based upon microstructure.

Based on the reason that I explained above, it is unlikely that these non-cast iron remains are manufacturing waste and produced accidentally during the melting process.

Besides the iron pieces found in excavated features, I have also found micro-remains that very likely are “hammer scale” (or *duanzao baopian* 锻造剥片) during the second season of excavation (Figure 5.24). This type of remains can serve as the best evidence for identifying the trace of smithing since they are usually distributed surrounding a smithing hearth (Sim 1988; Veldhuijzen and Rehren 2007). As the size of flakes is extremely small, it was collected by using magnet to screen and then through flotation[74]. The micro-structure of this type of remains show that they are completely corroded, but the layered structure of Fe2O3 and Fe3O4 is still clearly observable, indicating they should be the oxidized layer on the surface of an iron object that fell off during the hammering procedure. Although they generally belong to the category of manufacturing waste, hammer-scale can also be used during melting and refining process (Dillmann and L'Héritier 2007), which might be used as a supplementary evidence to prove there were other functions of the foundry besides smelting or remelting.

[74] During the project at Taicheng the time and budget limit did not allow me to screen all soil samples using magnet and hand-picking. I suggest the weight of hammer scale in soil samples can reflect to the original deposition of hammer scale to a certain extent. Therefore, during the excavation I collect soil samples—which were collected directly and not screened—from several features for a comparative study. And the collection method is as follows: first, I used a magnet to hand-pick and extract hammer scales as many as possible from soil samples. Second, all soil samples were processed through flotation to collect palaeobotanic remains. Then I and my workers used magnets to screen the heavy and light fractions again to extract the hammer scales that could not be collected by the first time screening. The hammer scales collected by these three methods (magnet dry-screen, light fraction, and heavy fraction) were then weighed and recorded.

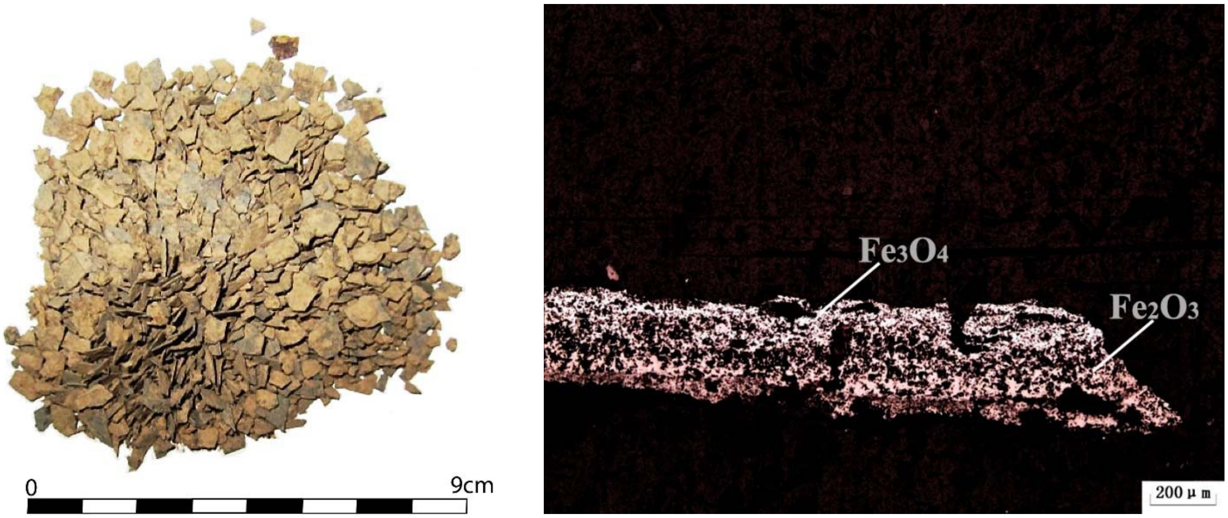


Figure 5.24 Hammer scale from H31 and its photomicrography

Summary

Having sampled and analyzed the technique of these samples, the nature of the most of them, however, is still difficult to determine given the preservation condition. Through synthesizing the shape of these samples with the results of metallurgical analysis, this study provides an additional line of evidence to address the nature of iron remains. Among the samples that are identified as decarburized steels, 71290 and 71170 (Figure 5.23:10, 11) belong to two special examples as they are a rectangular bar-shape object. In addition, these objects are thick and appear to have no sharp and clear-cut edges. In terms of the cross-section, 71170 belongs to eutectoid steel (Appendix A:6), and 71290 belongs to hyproeutectoid steel with widmanstätten structures (Appendix A:8). At other iron foundries that have known so far, molds that were used to cast iron rectangular bars or ingots (*biancai* 板材 or *tiaocai* 条材) for forging and hammering were quite commonly found. These two objects are very likely similar type of iron bar that would have been either molten or directly hammered into tools like iron knives.

In addition, certain pieces of fragments clearly are part of an iron tool. There are a total 6 pieces of iron samples that appear to be a C-shaped or S-shaped ring (e.g., Figure 5.23:2), which are very likely to be the ring-part of a ring-pommel knife. To confirm this idea, I sampled three pieces (71107, 71108, and 71169) of ring-shaped iron. According to the result, 71107 is completely corroded; 71108 is a piece of decarburized steel (Appendix A:10), and 71169 is wrought iron. Since the metallurgical studies in previous literature show that this type of knives was primarily made by decarburized steel—tools were either first cast into the final shape and then decarburized or made by forging decarburized steel—metallurgical study strongly supports my hypothesis that these objects should be part of ring-head knives.

The shape of sample 71203 is very similar to the tip-end of a ring-pommel knife, its microstructure shows that it is hypeeutectoid steel (pearlite+ferrite), indicating that it is highly possible to be a broken piece of knife. In terms of the last two samples that are identified as decarburized steels (71174 and 71186, Figure 5.23:6, 15), they are rectangular and may be some form of tools. It is important to note that, since the shape of 71186 is irregular, its nature would be very complicated as it would be a broken piece of an iron tool or an "ingot" that was not sufficiently decarburized.

Third, four samples in this study were identified as refined pig iron, but their original natures or the shape of tools were difficult to determine because they are all fragments. These "iron pieces" are all bar-shape objects, but the shape of their cross-sections are all different. In addition, their production or forming methods are not identical. 71117 was made by welding different pieces of refined pig iron and then through bending, which might have been a type of tool such as a chisel. 71126 was also made by welding and then hammering, indicating it probably belonged to a certain type of tool. In terms of the other two pieces of refined pig iron, their nature or function is more difficult to determine. These items could have been a raw material for hammering into a new tool. Also, they could have been fragments of broken tools, which would be recycled for remelting or hammering into new products.

Finally, according to the visual characteristics of pieces classified as the second category, certain fragments are flat with a curved profile, such as sample 71124 and 71168 (Figure 5.23:1,3), which might have been fragments of vessels judging based on the outlook of the fragments. According to metallurgical analysis, 71124 is a mottled pig iron (eutectic cast iron & spheroid graphite), and 71168 is a piece of wrought iron, probably a malleable cast iron. According to previous metallurgical study, iron vessels were more than likely to be cast and then reheated or annealed. Very likely, this type of curved and flat iron pieces were fragments of iron vessels and recycled as “scrap iron”, because molten cast iron has higher fluidity and can improve casting. Even though it is extremely difficult to classify the nature of all samples, metallurgical study can still prove that even samples that were identified as cast iron would have beeen scrap iron that were collected as raw material through recycling or remelting.

It is necessary to note that in the group of samples that I have not analyzed, the tool types of some of them can be identified for certain. The objects belonging to this category include a shocked spade (*kongshoucha*n 空首铲), spade (*cha* 锸), mortar, and halberd *ji*. They are all broken iron fragments, and none of them were preserved entirely. These items also are not directly relevant to iron production, and were unlikely to be production tools that were discarded by iron workers. Since these types of iron pieces have been found substantially from the foundry, and some of them appeared to be recycled-scrap iron for either remelting or hammering, this line of evidence substantiates my previous conclusion—scrap iron might consist of the majority of raw material resources for the small iron foundry. In other words, one major function of

Taicheng might have been to recycle scrap or corroded iron materials—which can include a wide range of objects from vessels to production tools to weapons—from the neighborhood community.

5.5 Conclusion: Techniques and *Chaîne Opératoire* of Iron Production

The classification and study of the assemblage lay down the foundation for continuing the discussion on the issue of labor division and organization. According to the study of manufacturing waste in terms of their variety and specific natures, I can first reconstruct *the chaîne opératoire* of the entire foundry (Figure 5.25). Below I introduce the major production steps and techniques reflected through analysis.

The operation of the entire workshop consists of several major components: mold/tuyère/furnace making, casting, as well as refining and hammering. It is necessary to explain here that, as blast furnaces and cupola furnaces required huge volume of energy, fuel and flux preparation (i.e., charcoal burning and grinding limestone) should also be a major part of the operation process, but the discussion of this procedure is difficult because other lines of evidence (e.g., geoarchaeology) must be incorporated for a detailed investigation.

Evidence related to mold-making processes is very tenuous in the assemblage but not completely absent. For instance, some over-fired or unfinished waste products were found. The production of molds already involved certain requirements in the organization and management of labors: after obtaining clay, workers might conduct sorting and prepare various types of clay for making molds as well as tuyères and furnace walls. Also, the variation in sizes implies that at least serveral groups or teams of workers were involved in the production of one single type of molds, an issue I will continue to explore in Chapter 7.

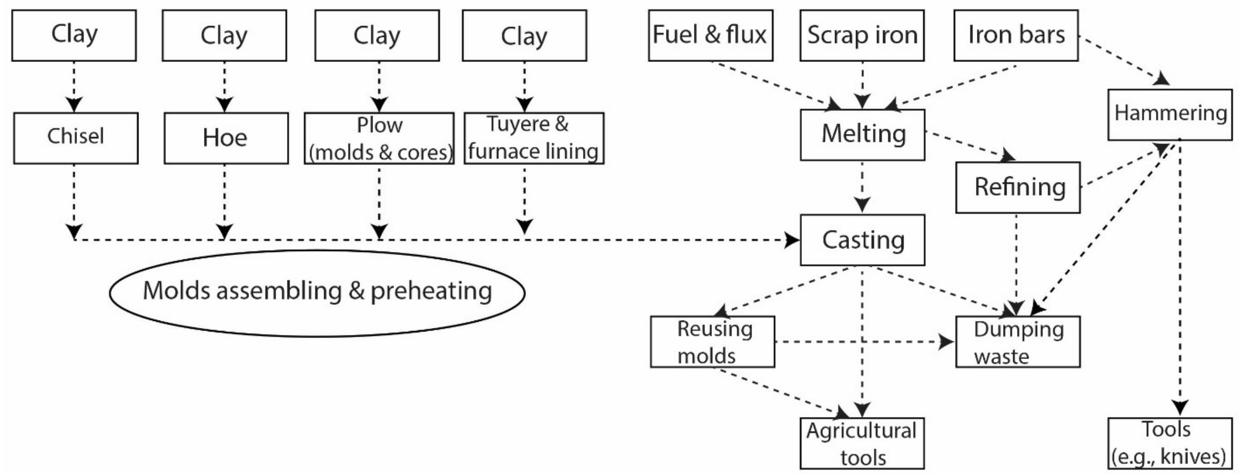


Figure 5.25 Flow-chart of the entire iron foundry
(The entire production might be subdivided into two sections. The section related to mold making and preheating should be associated with and belong part of the Taicheng foundry. Nonetheless, archaeological works have not identified any solid evidence in the excavated area yet)

The second step involved melting and casting. Analysis shows that the majority of slag belongs to cupola furnace slag or molten lining associated with iron melting, suggesting this foundry used cupola furnaces to remelt iron and cast objects. The chemical compositions suggest workers were familiar with and proficient in iron-melting in terms of the using of flux and controlling the environment to separate iron and slag. Furthermore, the consistency of major elements also suggests that these iron workers employed a relatively regular receipt in order to conduct the remelting process, which directly relates to other issues including the yield of iron and the quality of final products.

The step of iron refining and hammering is supported by several lines of evidence. First, different types of tuyères were identified. Because of the difference in the environment, different types of tuyères are required for the production. The study of remains shows that tuyère fragments include three types: top-blasting, side-blasting, and small-scale smithing tuyères. In addition, the discovery of hammer scale and refining slag were also the direct evidence of these procedures. In addition to manufacturing, the discovery of hammer scale indicates that workers at the foundry could repair iron tools for neighborhood through hammering and forging.

In terms of the final products at Taicheng, so far there were no ceramic molds for casting iron bars or casting tools other than hoes, plows and chisels found. In most large iron foundries predating the Han period, such iron bars were one major type of goods in the assemblage. Certain types of iron remains identified in the assemblage, including iron bars, iron vessels, and certain types of iron tools (e.g., spade), could not be produced directly by the small iron foundry. These iron tools were also not necessarily tools employed in iron production. No matter whether these objects were items used by iron workers or recycled scrap iron. Items that were made by hammering and forging and discovered from both the iron foundry and cemetery would have been produced directly by the iron foundry; instead they should be cast or produced somewhere else, probably outside the Guanzhong Basin, and then transported to the settlement alongside the moving of other resources like staple food or lacquer wares.

According to the analysis of iron remains, not only iron raw materials but also a wide range of iron tools discovered at the Taicheng site were imported from other parts of the empire, probably through the market exchange or trade network. In spite of multiple procedures that the foundry was involved, Taicheng was still not the type of iron foundries that could manage the entire *chaîne opératoire* of production entirely responsible for items discovered from the site-complex. This type of iron foundry had to rely heavily on the connections and network with other iron production centers, and could not conduct any production without the imports of materials or recycling from the outside.

Besides remelting and casting iron agricultural tools, this small iron foundry also recycled scrap iron and re-used old materials to make new goods. Taicheng was also a recycling center that collected old, broken and corroded items from the residence at Taicheng. The consumers (or provider) of the foundry also included the county government. As I discussed in Chapter 3, excavated texts show that each governor (*xianguan* 县官) had to inspect all "official implements" (*gongqi* 公器) in July and sell iron items before they were completely corroded. Perhaps helping and facilitating the local government to manage and maintain iron products was a more important function for the small foundry like the case of Taicheng.

For the small iron foundries like Taicheng, their roles, I argue, might be equivalent to the so-called "small iron-office" (*xiao tieguan* 小铁官) in later period when the iron monopoly policy was implemented. In fact, in previous study of iron foundries such as Wafangzhuang (Henan 1991; Li 1995), the report writers noticed that given that large numbers of bar-shaped iron pieces and irregular iron pieces had been yielded from the foundry—some of them even shows signs of burning or melting on the surface. Furthermore, they suggest scrap iron pieces were specifically collected for recycling and were the major type of iron resource for the iron foundry. In the Han period, the collection and recycling of scrap iron might have been conducted on a relatively large scale. Not only small foundries relied on recycling but also large foundries like Wafangzhuang that were relatively far from iron ore resources were supported by scrap iron. Sampling and metallurgical analysis in this sense provides a supplementary line of evidence to clarify and identify what kinds of iron products were recycled and how these scrap iron pieces were reused in production. This discovery also further supports the proposal mentioned in Chapter 4 that the iron foundry might not conduct any procedures related to iron ore smelting because there is no large iron ore deposit located in the Guanzhong Basin (Zhongguo 1996) and, more importantly, no iron ores or even ore processing tools have yet to be found from the foundry.

CHAPTER 6

NATURE OF LABOR, INTENSITY OF SPECIALIZATION, AND FAUNAL REMAINS

This chapter aims to address the connection between laborers, the structure of specialization, and faunal records from iron workshop sites. As I explained in Chapter 2, diet and meat subsistence can provide useful indicators with which to evaluate the intensity issue in craft specialization and the nature of laborers (e.g., see cases in Gidney 2000; Redding 2010). Full-time specialized workers have to obtain meat that is produced by other members and distributed through an exchange system, sometimes involving a segregation of each procedure in the entire meat production in terms of the personnel and location. According to Zeder (1988), indicators of such specialized system can be accessed in faunal records through the management and distribution in the range of species, body-part representation, and age profiles for slaughtering. The variability in the degree of specialization can also be represented by selection and distribution patterns in the archaeological evidence.

Models drawn from case studies of urban food-chains in other regions, such as the faunal records in Colonial North America, can facilitate the evaluation of indicators of specialization for two major reasons. First, urbanism and craft specialization are a pair of concepts that are inextricably linked to each other. Craft specialization, especially in large-scale workshops, needs to rely on the labor forces and transportation systems in urban centers to procure necessary resources and raw materials. As a result, both urban centers and highly specialized workshops need to rely heavily on other members to procure meat resources. Second, in the context of Colonial North America, commercial economy and market exchange were well developed and played a key role in economies. They are, therefore, very comparable to the historical context of the Han period as I discussed in Chapter 4. If the patterns in faunal remains match the scenarios of husbandry, slaughtering, and distribution patterns in Colonial North America, the zooarchaeological research can then convincingly demonstrate that iron workers at Taicheng belonging to the category of "full-time" specialists—who spent most of their time in the iron craft industry vis-à-vis other production activities.

Nonetheless, many other factors need to be taken into consideration even if the faunal records from a production site look similar to the theoretical model of an urban food-chain. Bone remains are always subject to factors including not only the supply of food but also taphonomy, occupants' status, ways of food preparation, and so on. In addition, the patterns in faunal remains also are related to the extent in which iron workers relied on the specialized meat production system. For these reasons, the analysis of animal remains in this chapter will try to address three interrelated questions: 1) Do animal records reflect a specialized meat production and distribution system that looks similar to patterns in an urban food-chain? 2) If so, what are the other factors that would potentially skew or bias the taxonomic and body-part assemblages? 3) Additionally, even if the patterns indicate a specialized meat system, was the type of specialization in food production very intensive and entirely dependant on other individuals who were meat producers?

6.1 Framework of Specialized Meat Production System

This section considers several factors that influence the formation of the zooarchaeological records in an urban setting. A discussion and review of scholarship on this issue will help develop a theoretical framework to translate patterns in the faunal record into evidence illustrating how labor was organized and the degree of specialization.

The primary principle in the study of urban food chains is often based on assuming dichotomy between urban and rural subsistence strategies. In an urban setting, since many tasks are outsourced, and many hands are involved in meat butchering and distribution (Landon 1997:160), the way in which meat was supplied might be characteristically different from its rural counterpart. In such a scenario, low frequency of wild foods[75] such as game animal and wild plants is expected in the assemblage because food products were not raised or hunted by urban residents. In addition, non-local and exotic food items would be more likely brought into the city through a market system (e.g., Bowen 1992, 1994, 1998).

Furthermore, in terms of the body-part assemblage, Reitz's study (1986) of faunal remains from sixteen sites in Georgia and South Carolina, which include both rural and urban contexts, demonstrated that faunal assemblages in rural areas always show more diverse patterns than their counterparts in urban centers. In a market economy, meat is professionally butchered and sold by retailers. As commercial slaughtering of large mammals is always prohibited within or far from the area of slaughtering sites, more often than not slaughtering waste and non-meat anatomical elements are rarely found or are of low frequency (Henry 1987a, b; Schulz and Gust 1983). As a result, the body part assemblage in urban contexts often concentrates on certain meat elements.

[75] This by no means indicates that wild species would be completely absent in urban archaeological records. Based on the example of Charlestown, indigenous wild animals that were able to adopt to the growth of the city and animals that were attracted to the urban center were found in the assemblage (Reitz and Zierden 2014; Zierden and Reitz 2009). Thus, it will oversimplify to view all non-domesticated animals in an urban setting as the result of hunting wild games.

Another signature of urban food-chain is detected from the kill-off pattern. Based on the study of husbandry in Colonial New England, Bowen (1998) proposed that the increasing market for beef and emerging market for wool would eventually lead to the commercial and specialized husbandry. The kill-off pattern of cattle in archaeological contexts, for instance, should show that the majority of cattle was killed during their prime along with the growth of a more specialized and intensified animal husbandry. For these reasons, taxonomic assemblage, body-part representation, and kill-off pattern in urban contexts are more likely to demonstrate a pattern distinctive from those in rural contexts (Landon 1996).

The second principle is that, in a market economy where most people do not have direct access to food, income is an important factor in consumption decisions, which in turn affects the archaeological record (Huelsbeck 1991; Landon 1996). Meat cuts from different body-parts sometimes would be ranked differently and thus consumed by members of different status (Schulz and Gust 1983). To wit, the higher status the members are, the more meaty portions or more diverse meat choices these members can consume. Two case studies in different time and space provide a case in this point: one is Schmitt and Lupo's ethno-archaeological study (2008) showed that richer families consume more large mammals in farmers' groups in Central Africa, while Milne and Crabtree (2001) demonstrated the consumption pattern of the working class in 19th century New York was distinctive from "higher-rank households." Many other studies, however, have called for caution on *the simple* assumption that occupants of a site with low social or economic status necessarily consume fewer meaty portions and, consequently, more fragments associated with low-valued parts elements are always a reliable indicator of lower status (Crader 1989; Crader 1990; Henn 1985; Lyman 1987; Schmitt and Zeier 1993).

This idea, in fact, is based on the assumption that portions of carcasses which are worth higher price today carried the same value in the past. Nevertheless, this may not always be the case. As case studies of cattle and pigs (Reitz 1987; Reitz, et al. 2006; Reitz and Zierden 1991) in Charlestown—an urban context dating between the 17th and 19th century in South Carolina—demonstrate, the ratio of meaty and non-meaty portions in the assemblages does not always present a meaningful pattern between contexts associated with economically differentiated classes. Instead, in an urban context, the selection of products was also subject to other social factors such as the functional differences of sites, cultural preferences for food, market availablity, garbage discarding system, etc. (Henry 1987b; Huelsbeck 1991; McKee 1987; Rothschild 1989; Rothschild and Balkwill 1993; Schiffer 1987). These economic factors and the issue of income would play roles at the same time in shaping and transforming the animal remains that eventually were deposited in archaeological contexts.

Finally, since bones in an urban context are the results of purchase events, how the carcasses were butchered, cut, selected, and distributed were subject to factors such as meat preparation strategies or consumer group size. For instance, Chichkoyan's (2013) study showed that faunal remains in the midden associated with a restaurant and shipyard buffet in Argentina during the 19th century represented two types of purchase patterns: retail market and wholesale. The two patterns are generated because of the differences in cuisine and the scale of consumers between a small restaurant and a buffet. The small restaurant purchased retail meat cuts that were smaller and had fewer bones (e.g., ribs, sirloin, and round in appendicular portions). These types of meat could be easily adjusted for different customer orders. In contrast, the buffet adopted a wholesale model purchasing large meat cuts such as an entire hind limb. Since its consumer group was larger and the restaurant offered more pre-set dishes, the buffet did not need small but adjustable meat cuts as a small restaurant. As a resulty, the buffet would generate higher density of limb-bones and more identifiable bone specimens in archaeological contexts. Although these models might not be directly applied in the case study of Taicheng, the size of meat cuts and decisions underlying the acquisition patterns of meat provide useful information with which to investigate the scale of the working community through a comparative study.

Similar to urban residents, a working community specialized in a craft industry in a full-time manner has to rely heavily on its neighbors or food markets to bring in meat instead of raising livestock or processing the butchery by themselves. The consumption of full-time specialists would generate patterns in faunal remains similar to urban subsistence in many manners. Since many hands have to be involved in the processes, from raising and killing livestock to butchering and distributing meat cuts, the meat consumption of these workers would then be subject to the same factors such as cost-benefit considerations, monetary ability, and access to meat markets. For a community of specialized worker, their meat consumption would presumably generate certain patterns similar to the urban food chain as follows:

#1 A taxonomic representation is dominated by domestic livestock, and relatively low frequency of wild game is obtained through hunting;

#2 Certain elements, especially the less meaty portions like the head and lower limb bones, tend to be underrepresented because production and consumption was segregated and an increase in transportation costs;

#3 A age profile of the faunal remains indicates highly selective kill-off pattern in livestock iin order to maximize either the meat yield or extract secondary products;

#4 Diffrences in cuts of meat or species depending on the social status of the working community (e.g., the patterns consumed by working classes are different from that generated by upper or middle-class members);

#5 Butchery patterns reflect the size of the worker community, because the purchase of meat cuts from the market and their transportation have to take the cost-benefit and economical factors into consideration.

The sections below will evaluate the archaeological evidence to determine if the faunal records from Taicheng match these five theoretical patterns.

6.2 Status of Laborers in Textual Records

Since market supply and economic status of workers were two key factors in understanding the pattern of archaeological records (# 4 and #5), this section tries to first address these two fundamental quesitons regarding the nature of workers' identity and the nature of laborers in the iron industry within the Han historical contexts. Unfortunately, specific records about the organization of the iron industry are rare and sporadic in historical documents. For instance, iron works were mentioned in *Hanshu*[76] just because of an accident associated with the explosion of a blast furnace. These events were viewed as a sign from Heaven warning of political struggles in the royal family during the reign of Emperor Wu and Emperor Cheng (51-7 BCE). For small workshops such as Taicheng, historical records on the nature and organization of iron workers do not exist.

[76] *Hanshu* 27A.1334.

The limitation in texts requires us to contextualize the issue in a broader discussion. In fact, the status of iron laborers is approachable through exploring three related issues: the system of state-controlled labor, labor wage, and market prices of food. By marshalling and bringing in textual information of these aspects together, I will move forward and raise certain hypotheses about what kinds of specific patterns in faunal assemblages would be generated by a community of workers, according to the relationship between the iron industry and the government, laborers' identities in craft production, their wages, and the prices of meat and other staple foods. These hypotheses will then be tested against zooarchaeological record to investigate whether the faunal remains from Taicheng match the consumption of full-time laborers in the Han period.

During the Han period, labor forces, especially those associated with stated-sponsored projects, in craft production or construction could be categorized into three types: *gong* 工, *zhu* 卒, and *tu* 徒. *Gong* usually refers to skillful workers who had specialized technique or knowledge and, thus, enjoyed a better social status, while the other two categories, *zhu* and *tu*, mean workers involved in more intensive but low-skill laboring jobs (Chen 1980:124, 193, 196; Yu 2006). For some industries, the knowledge could be passed down only inside the *gong* family; thus *gong* might even have been an inherited social status and occupation. In contrast, *tu*, or *xingtu* 刑徒, in transmitted and excavated texts is equal to convict laborers, who committed crimes and were sentenced but could not afford the fines.

The legal system of the Qin and Han were designed very specifically to define the sentences of various types of crime (e.g., stealing, murdering, and damaging government-owned implements). These sentences include body-punishment (*xing* 刑), fines (*jin* 金), and time serving as convict laborers such as *lichengqie* 隶臣妾 and *chengdanchong* 城旦舂 (Barbieri-

Low 2007:220). In general, the former type of convict labor was a lighter sentence and did not involve any body punishment (e.g., shaving hair or beard). This type of laborer could be assigned to agricultural production, food processing, herd raising, and, most importantly, craft production (i.e., for bronze weapons and iron goods) (Wu 2012). The latter form of convict labor (*chengdanchong)* refers to lower status workers who did not even own any personal property. They were often marked by "stigma" through body punishment and were in charge of heavy and intensive labor works. Theoretically, if criminals had the financial power they could redeem their crimes in cash all in once (Yates 2002). But for those who could not afford the sentence fines, the criminals needed to work for the government (e.g. iron production) for a certain period of time until their fines, which were calculated based on the wage of a labor per day at the labor market, were met by their laboring time.

Zhu literally means corvée labor. During the Han period, each adult man has to serve as a corvée for a wide range of purposes from constructing canals and palaces to guarding frontiers. Although each time serving as a corvée would last only couples of days, the total times serving as corvée labor in any given year would vary widely (Zang 2012:144-152). Official-sponsored workshops also used corvée labor for low-skill jobs. In this case, a corvée laborer usually served the workshop nearby or in his county (Yu 2006). For *gong* workers, sometimes they were also required to serve as corvée laborers in official workshops, but the duration of other forms of labors (e.g., guarding frontiers) would then be reduced because they were more valuable laborers in production.

It is important to note that, although the social status of *lichengqie* and *chengdanchong* is lower than commoners, they were not at all slaves. The issue of "slavery" during the Early Imperial China in the labor system for state-sponsored industries and projects has attracted a lot of attention in previous scholarship. For instance, Martin Wilbur (1943a, b) long ago synthesized evidence mentioned in texts such as *Discourse of Iron and Salt* , and discussed the status of slave labor and addressed the types of labor mentioned in texts. He concluded that, in the Han period even after the salt and iron industries became government monopolies, the government basically employed a large amount of corvée and convict laborers in the industries as well as large-scale project such as the construction of mausoleums. Slaves, or laborers serving non-redeemable work[77], were primarily used as servants in household or smaller-scale handicraft industries like textile productoin. Slaves, however, were rarely employed on a large-scale in the state-sponsored industries and projects associated with iron and salt (e.g., Barbieri-Low 2007; Yates 2002), which is remarkably different from the labor system in other empires such as Rome that widely employed slave labor in various production and construction (Scheidel 2011, 2012; Yates 2002).

Therefore, it is legitimate to view that laborers in the production of iron and salt during the Han period were wage-laborers in a broad sense. These laborers worked for wages, food, or rations in return, and their "labor value" was calculated based on the average ratio of wages at the labor market. The social or economic status of most workers might be lower than a commoner, but experienced workers or skillful artisans would be hired for producing prestige goods or operating the most important smelting process in iron production at higher wages. Only after the implementation of the salt and iron monopoly policies was the entire iron industry—both the most labor-intensive section such as mining and smelting and the less labor required sections such as iron smithing—all under the control of iron officials and the superintendent of agriculture in the central government, leading to widespread hiring and the use of convict or corvée labor. Also, the numbers of skilled workers was by no means comparable to the scale of

[77] For the detailed differentiation between slaves and other types of laborers during the Early Imperial China, please see the discussion in Yates 2002:314.

other hired laborers and convict or corvée laborers in various types of construction and production. By then, serving a local workshop organized by the government routinely became one among the many other types of labor taxes a commoner was required to pay[78] .

For small ironworks like the case of Taicheng, it is not certain whether the situation of large iron foundries was applicable to the case. More importantly, since the site predated the monopoly policy, the foundry might not necessarily have employed convict or corvée laborers. But no matter whether the iron foundry was run by the local government or, more likely, run by a private merchant, most workers required in iron production were likely hired as forms of wage labor either in terms of free laborers or convict/corvée laborers.

Based on this understanding, I propose that textual evidence about food prices and labor income can shed a fresh light on the economic status of iron workers. As I mentioned earlier, how much meat or food a full-time worker can buy is determined by how much he or she can earn. In the Han period, or even earlier, the labor force had already become a type of purchasable product in the market. Accordingly, the prices for a hired laborer were mentioned several times in a contemporary mathematic book called *Nine Chapters on the Mathematical Arts* 九章算术 (Guo 2009; Shen, et al. 1999). As a mathematic "text book," this document used many questions from daily life to introduce mathematic methods and solutions for these issues. Important pieces of information about prices are, fortunately, preserved in texts of the nine different chapters. This book was annotated first by Liu Hui 刘徽 during the 3rd century CE close to the end of the Eastern Han period, and the basic contents might have been complied by Zhang Cang 张苍 and Geng Shouchang 耿寿昌 during the Western Han period. Whether the contents reflect prices

[78] *YTL*, "Hindrance to farming", trans. Gale 1966: 33

during the Western Han period or information from the Warring States period is a debatable issue[79], but the information of prices and wages mentioned in texts has its undeliable value in investigating the issues mentioned above.

The information about prices from the Han mathematic book has also been systematically collected together in several scholarly works (e.g., Song 1994). Such investigations have reconstructed almost every asepct of the prices of good during the Han period. The discussion below will thus primairly be derived directly from these synthetic works. To address the living standards of workers, the first question to address is the average wage per day for an average laborer. According to Song Jie's work (1994:84-85), the market price for a wage labor per day—no matter what type of occupations—generally ranged between 5 and 12 *qian* (or coins) in the *Nine Chapters on the Mathematical Arts*. It is noteworthy that the Shuihudi bamboo slips, which were found in a local official tomb of the Qin Empire in Yunmeng, Hubei, mention wages for corvée laborers that fall within this range:

"*Per day they work off eight cash; those fed by the government work off six cash per day. For those who work off (their obligations) in government storehouses, and who are fed by the government, (the rations are) for men one third (of a tou for the morning meal and again for the evening meal); for women one quarter"* ("Statutes concering the Controller of Works", trans see Hulsewe 1985:p.68, A.68)

Therefore, this range of wages in *Nine Chapters on the Mathematical Arts* seems to come from some reliable resources, which at least reflects labor wages during the Qin period. But was

[79] Given the uncertainty of the date when the book was compiled, there is a long debate about this. Since recent discoveries of bamboo slips prove that mathematic books which follow a similar format were already formed during the Warring States period, the information mentioned in texts might be slightly different from that in the Han period. See (Guo 2009; Guo 2010)

the range of wages also applicable to the Han period? According to another piece of excavated texts from Zhangjiashan in Jianling, Hubei, dating to the Early Western Han period, for those who tried to escape the service of corvée labor, they had to be fined 12 *qian* per day as punishment[80]. Based on this evidence, several scholars agree that the average range of labor wages during the Western Han period stayed the same (Ding 2009:92; Lin 1999). Although one can still argue that this conclusion might not be the case throughout the entire Western Han period because of inflation, this piece of information, as it is contemporary to the Taicheng case, is relevant enough for the purpose of the discussion here. In other words, during the Early Western Han period, the wage for a labor, no matter whether he or she was hired by an individual merchant or worked for the government as a convict laborer, should fall within the range between 5 and 12 *qian* per day.

The second question that immediately follows the standard price of wages is the amount and types of food that would have been purchased according to the average wage per day. Records in transmitted texts and excavated records also provide invaluable information in this aspect. During the Han period, a wide range of domesticated animals (or animals relying on human's intervention)—including hare, dogs, pigs, deer, cattle, and sheep—would have been consumed in daily life, elite feasting, as well as mortuary rituals (Hayashi 1975). But for commoners, having meat (either pork or beef) would be a luxury meal since meat was relatively expensive during the Han period, as Yu Ying-Shih (1977) pointed out. In the table below (Table 6.1), I list all the prices of major types of livestock mentioned in the *Nine Chapters on the Mathematical Arts* and summarized by Song's (1994) work. In the same table, I also list the prices of livestock and fish in Han wooden slips from Juyan and other frontiers sites in present-day Gansu, which have been

[80] *Zhangjiashang* 2001: 186, "Statutes on Noncompiance" (Xinglv 兴律).

studied in many previous scholarly works (e.g., Liu 1999). The comparison can even help determine how frequently a family of commoners could have meat in their daily meal.

Not surprisingly, the figures in Table 6.1 shows that, in comparison with our modern world, the price for each livestock was much higher and more expensive in the Han period. For instance, there are two prices for a chicken, 23 and 70 *qian*, mentioned in the *Nine Chapters on the Mathematical Arts*. According to bamboo slips, the price per chicken was 36 *qian*, which is relatively in the middle ground of the two other prices. But even considering the lowest price, a chicken would easily cost an average laborer 2~4 days of wages. Fish was more affordable than other livestock for commoners, but each one would still cost from one-fourth to half of the daily wage of a laborer. For a medium size mammal like a pig or a caprine, its price as per animal was at least equivalent to monthly wages or even more of a laborer.

Of course, these prices listed in Table 6.1 are the prices for "wholesaling" from farmers; merchants or middlemen would sell the livestock at much higher prices at the market. In an urban setting, residents would rarely buy a whole live cattle for beef at one time. It is also our common sense that the "retail-selling" price of a meat cut per unit would be higher than the unit price of meat from an entire livestock. The price for livestock as a whole, however, can provide a comparative reference with which to infer the market price of meat per unit. For instance, if one cattle can generate about 610 pounds of "on the rail" meat[81]—which is the maximum amount of meat (including bones) that a professional butcher can get from a cattle in modern butchery industry, the cost of beef per *jin* 斤 or 250g (Sun 1991), would be roughly about 1.08 *qian*. This

[81] This figure is according to the Oklahoma Department of Agriculture, Food, and Forestry. http://www.oda.state.ok.us/food/fs-cowweight.pdf

price is just calculated solely based on the lowest price of a cattle in the list; in reality, the price of beef per unit should be much higher, and never be lower than 1.08 *qian*.

Table 6.1 Price of livestock mentioned in texts (unit: *qian*)

Types of livestock	Price for each animal *source Song 1994	Price for each animal source: Liu 1999
Horse	5454	
Cattle	1200/1818/3750	2500/3000
Sheep/goat	150/177/500	250
Pig	300/900	
Dog	100/121	
Chicken	23/70	36
Rabbit	29	
Fish		3.33

*in the document, usually several prices were listed for each type of livestock, probably related to the fluctuation in the market

Table 6.2 Price of *su* 粟 (millet or husked millet) and meat per unit mentioned in excavated texts

Price of millet 粟 (per *dan* 石, 1 *dan*=0.565 US Bushels)							
median	110	Average	541.22	lowest	77.2	Highest	3971

Price of meat (per *jin* 斤)*							
median	5.25	Average	5.62	lowest	2.1	highest	11.7

*for the records that used *gu* 谷 as the exchange media, I use the record 1 *dan* 石=35 *qian* to calculate the equivalent price. There are four different prices for *gu* 谷 in the unit of *dan* 石 mentioned in excavated texts: 5, 35, 1200, 4000 (Liu 1999). Except the second number, the other three appear to be too fluctuated and alienated from the average price for each 石 of other stable food.

Fortunately, the bamboo slips from the Hexi corridor along the frontier lines such as Juyan (Lao 1957; Loewe 1997) also provide more detailed information to address the prices of retail selling food. Based on the published excavated records, scholars like Liu Tseng-kuei (1999) and Wei Xiaoming (2010) have extensively collected information about these type of prices mentioned in bamboo or wooden slips. According to their works, not only meat (probably beef) but also various types of organs such as stomach, intestine, heart and even the head of a cattle in the Hexi region were sold at the market at specific prices. Without any doubt, the meat market was a major channel to distribute meat and daily necessities in the imperial frontier; in the capital area meat markets should be even more developed and commoditized because it was the center of the entire imperial transportation system.

Similar to the livestock prices mentioned in texts, meat and staple food prices fluctuated according to wooden slips. In general, the price of meat cut per *jin* 斤 (250g) ranges between 2.1 and 11.7 *qian* with a median of 5.25 *qian* (Table 6.2). The lowest price of 2.1 *qian* is derived from the record using unhusked millet (*gu* 谷) as an exchange medium and is converted by using the number 1 *dan* 石=35 *qian*. But this range of meat price appears to be very unlikely; it is too low in relation to the minimum meat price of 1.08 *qian* per *jin* mentioned above. Instead, since the average and median prices of meat per unit were both about 5 *qian* during the Western Han period, I tend to view this as a more reliable number. Furthermore, given the highy developed husbandry practices in the Hexi region and northwestern frontiers of the empire, theoretically, the meat price per unit for commoners would unlikely to be lower than the meat price in the capital area. In other words, even though regional variability of meat prices would exist, meat (beef and pork) price per *jin* unit in the Guanzhong area would probably be about 5 *qian* or slightly higher.

As the same time, each family needs to first secure staple foods; thus the staple food price is an indispensable factor in the discusison of purchasability. The *Treatise on Food and Money* in *Hanshu* mentioned the price of each *dan* of *gu* (or *su*) during the Western Han period fluctuated between 5 and 300 *qian*[82]—which is also the reason I select the price 35 *qian* per *dan* of *gu* (unhusked grain) mentioned in excavated texts to calculate the meat price. For *su* 粟 (husked

[82] *Hanshu* 24A.1125, 1141, 1142.

millet), each *dan* fluctuated more frequently and ranged widely, with the mean of 541 *qian* and median of 110 *qian* (Table 6.2). Also, according to *the same chapter,* each individual required 0.83 *dou* 斗 (ibid:141) (1 *dan*=10 *dou*) of staple food to survive. Having these two important conditions, the cost of staple food to feed a family of three would be roughly as follows:

Cost of staple food per day = 0.83*3*(30~80)/10=7.47~19.92 (*qian*)

According to the formula, the income of a laborer per day was, in fact, barely enough to purchase the amount of staple food, or 2.5 *dou* of unhusked millet, for the entire family of three. Going back to the core question of how frequently a common family during the Western Han period would have the chance to eat meat, the answer according to the number of prices appears to be very low. Based on the relatively low wage of a laborer per day and price of *gu* per unit, a laborer, and probably a farmer as well, might find it impossible to afford having meat (beef, pork, and mutton) even occasionally, since the prices of meat and stable food were relatively high in relation to the pay for an average laborer. For each family, there were also other necessities such as salt, vegetable, clothes, etc. Therefore, chicken perhaps was the most fundamental livestock for commoners; but even having chicken with vegetable might have been a luxury meal for most commoner families and could not be affordable for daily consumpotion (Yu 1977:74-75).

Even though the Taicheng foundry was small, its operation still required certain number of workers devoted to various stages of production from the preparation of raw material, fuel, and molds, to the process of remelting and smithing, and to the processes of moving final products and dumping waste. No matter whether Taicheng was a private foundry or an official one run by the government, most of the workers should be paid by the marekt ratio of wages according to the range mentioned in texts. Here I raise two hypotheses regarding the potential patterns in faunal remains consumed by the worker community in order to test if archaeological records can prove if this was the case:

I. *In the midden or archaeological contexts associated with low-status workers, the faunal remains might be extremely few*.

The majority of commoners in the Western Han period—including wage labors and farmers who self-sustained themselves—did not get much access to meat resources in their daily diets, except for special occasions like festivals (Bodde 1975). In general, meat would be too expensive and rare for commoners in their everyday lives. Archaeolgoical evidence such as miniature models in Han tombs demonstrate livestock (primarily pigs and chicken) were commonly raised in commoners' backyards (Wang 1984), but these livestock could have been sold as an important means to buffer the impacts of bad seasons or emergent events for the family. Since commoners rarely consumed meat, faunal remains, especially those related to large mammals, might have been essentially absent in archaeological contexts.

II. *In considering commoners' social and economic status, the most common taxa of domesticated livestock very likely would be poultry.*

Meanwhile, since wage workers during the Western Han period were paid at a relatively low rate, even if they could have been able to afford meat, the main option would be chicken. In other words, in contexts associated with a worker community that consist primarily of hired laborers in an urban area, faunal remains would probably just include poultry and fish. Needless to say, these two ideas might just describe an idealized situation; other factors also need to be taken into consideration such as the duration of production activities (or seasonality) to fully considerate the hypothesis.

6.3 Taxonomic and Element Assemblages

Table 6.3 Taxonomic representation at the Taicheng foundry

		NISP Count	NISP %	Weight g
Bos taurus	Cattle	97	18.8	7803.1
Sus scrofa	Pig	49	9.5	872.4
Ovis aries/Capra hicus	Sheep/goat	37	7.2	686.8
Canis sp.	Dog	73	14.2	769.0
Equus caballus	Horse	19	3.7	1717.1
Odocoileus virginianus	Deer	3	0.6	141.3
Rodentia	Rodent*	14	2.7	<1
Unidentified fish		3	0.6	<1
Gallus gallus	Chicken	3	0.6	5.1
Anas sp.	Duck	1	0.2	2.5
Unidentified birds		7	1.4	1.7
Large mammal		59	11.5	727.4
Medium mammal		120	23.3	430
Large-medium mammal		12	2.3	21.1
Small mammal		18	3.5	<1
Total		515	100	13177.5

***rodent that was found in the assemblage may be intrusive**

Before digging into the details of the faunal records and integrating them into the textual information about meat costs and wages, I first introduce the data collection approach in my fieldwork and analytical methods. In order to systematically collect remains during the excavation, the fill from each pit was screened and passed through 1.5x1.5 cm mesh screen. Specimens that were seen with naked eyes were collected. In addition, soil samples (for the detailed records see Figure 7.18 in Chapter 7) were taken for flotation in the second season to understand to what extent the small bones and bone fragments were underestimated. Also, in the analysis below I will convert the data of NISP to MNE and recovery rate to study the percentage of different body parts presented. In this study, MNE refers to the minimum number of skeletal elements necessary to account for an assemblage of specimens of a particular skeletal element or part of portion (for definition see Landon 1996; Legge and Rowley-conwy 1991; Lyman 2008), and was calculated based on the NISP of each anatomical unit. According to the MNE, the recovery rate was calculated to indicate the relative abundance of different anatomic units. Here I define the recovery rate as "the percentage of the expected elements actually recovered, given the minimum number of animals (elements) represented in the assemblage." (Landon 1996:47).

Faunal remains in this study primarily came from sixteen features of the foundry dating to the Western Han period[83]. Given the small scale of the site, it is not surprising to note the number of identified specimens is just 515. In Table 6.3 I show the NISP values of all species identified. Cattle and dog clearly were the two most important species in the diet of the worker community. Pig and sheep/goat also were substantially consumed in the diet, and the latter are very likely goats according to diagnostic features (Boessneck 1969). Other species identified include horse, chicken, deer, and fish. It is noteworthy that horse in the Han period was the most valuable livestock. As mentioned in Chapter 4, bamboo slips mention that when a horse and cattle belonging to the government died, the local official had to immediately sell every part of it body (e.g., meat, skin, and horn) and to collect the cash of all its values[84]. Horse bones that were found at the site might originally be the livestock owned by local government but sold out to the meat market when they were old or dead instead of being raised for meat production.

[83] The faunal remains from features predating or postdating the Western Han period will not be included in the study.

[84] *Shuihudi*, "Statutes on Stables and Parks", trans. Hulsewe 1985:28-29, A9.

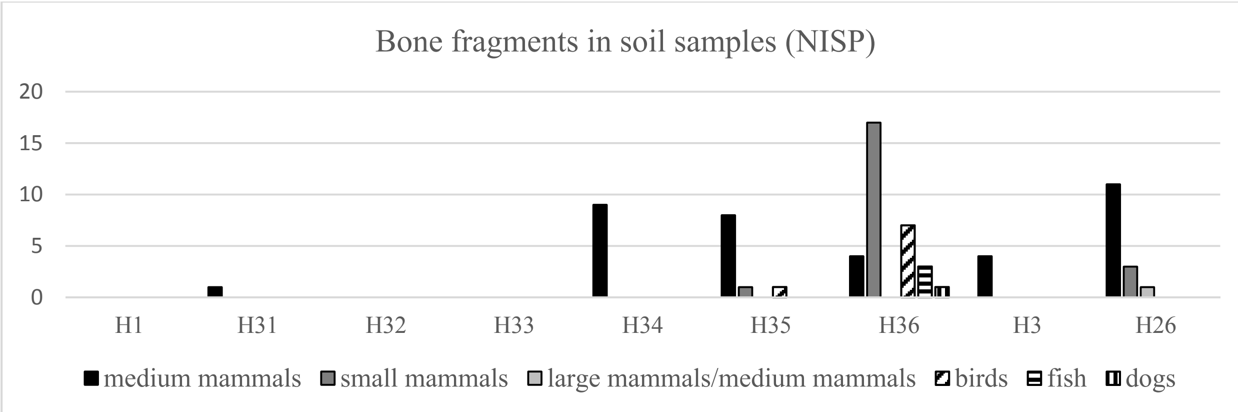


Figure 6.1 Bones that were found in collected soil samples for flotation and screening

Small bone remains (e.g., bird and fish bones) were collected primarily through flotation[85], but the number of fish and bird bones found is very low (Figure 6.1). Given the fact that most small bone fragments were basically unidentifiable, and that fish was only found in one feature, the occasional appearance of small bones in flotation samples indicates that their frequencies are not entirely subject to the bias of collection methods. It seems safe to conclude that about 90% of faunal remains (not including samples that were identified based on size) associated with the foundry belong to major domestic mammals. Only about 10% of specimens belong to bird, rodents, fish, and deer. In the 11 bird specimens, two specimens are identifiable to species: one is a chicken ulna and the other one is a duck radius. Since fish and deer only make up less than 4% of identifiable specimens, resources that could have been obtained through hunting or fishing only present a very small component in the assemblage. Although the site is adjacent to the Wei River, the low presence of fish in the workers' diets might reflect the long tradition of fish playing a limited role in subsistence in the Yellow River valley since the Neolithic period (Yuan and Flad 2008).

[85] I will discuss the volumes of soil sample subject to flotation in Chapter 7.

Table 6.4 Minimum numbers of elements and recovery rates for cattle, dogs and pigs at the Taicheng foundry

	Cattle %Recovery rate	MNE		Dog %Recovery rate	MNE		Pigs %Recovery rate	MNE
Skull (Frontal)	44.44	2	Skull (Maxilla)	100.00	6	Skull (Maxilla)	75.00	3
Mandible	33.33	3	Mandible	58.33	7	Mandible	100.00	8
Axial	22.22	1	Axial	16.67	1	Axial	0.00	0
Atlas	0.00	0	Atlas	0.00	0	Atlas	0.00	0
Cervical	3.17	1	Cervical	4.76	2	Cervical	0.00	0
Thoracic	0.00	0	Thoracic	1.28	1	Thoracic	0.00	0
Lumbar	0.00	0	Lumbar	2.78	1	Lumbar	0.00	0
Sacrum	44.44	2	Sacrum	16.67	1	Sacrum	25.00	1
Scapula	22.22	2	Scapula	8.33	1	Scapula	12.50	1
Proximal humerus	0.00	0	Proximal humerus	16.67	2	Proximal humerus	0.00	0
Distal humerus	33.33	3	Distal humerus	33.33	4	Distal humerus	12.50	1
Proximal radius	100.00	9	Proximal radius	33.33	4	Proximal radius	0.00	0
Distal radius	44.44	4	Distal radius	33.33	4	Distal radius	0.00	0
Proximal ulna	33.33	3	Proximal Ulna	33.33	4	Proximal Ulna	25.00	2
Distal ulna	22.22	2	Distal Ulna	25.00	3	Distal Ulna	0.00	0
Carpal	9.26	5	Carpal	16.67	0	Carpal	0.00	0
Pelvis	33.33	3	Pelvis	41.67	5	Pelvis	37.50	3
Proximal femur	11.11	1	Proximal femur	50.00	6	Proximal femur	0.00	0
Distal femur	11.11	1	Distal Femur	58.33	7	Distal Femur	0.00	0
Proximal tibia	0.00	0	Proximal tibia	16.67	2	Proximal tibia	0.00	0
Distal tibia	22.22	2	Distal tibia	33.33	4	Distal tibia	0.00	0
Calcaneus	22.22	2	Calcaneus	0.00	0	Calcaneus	0.00	0
Astragalus	0.00	0	Astragalus	16.67	0	Astragalus	0.00	0
Tarsal	11.11	1	Tarsal	0.00	2	Tarsal	0.00	0
Proximal metatarsus	44.44	4	Metatarsus	3.33	5	Metatarsus	0.00	0
Distal metatarsus	55.56	5	Metacarpus	8.33	1	Metacarpus	0.00	0
Proximal metacarpus	66.67	6	Metapodia	1.67	2	Metapodia	1.25	1
Distal metacarpus	33.33	3	1st phalange	0.00	0	1st phalange	0.00	0
Metapodia	11.11	2	2nd phalange	0.00	0	2nd phalange	0.42	1
1st phalange	11.11	4	3rd phalange	0.83	1	3rd phalange	0.00	0
2nd phalange	5.56	2						
3rd phalange	5.56	2						

Fragments that cannot be identified down to species levels are classified according to size categories. Large mammals may primarily belong to cattle and horses, while medium-sized mammals are possibly pigs, caprines, and dogs. Even though the NISP values of these fragments are relatively high, the weight of fragments that were assigned to size categories only accounts for 10~13% of the total weight of all identifiable specimens. In other words, bones of mammals from the site that are fragmentary and are not identifiable only present a very light portion in the total assemblage.

To better depict the acquisition pattern of meat cuts, I convert the MNE of the three major species: cattle, pig, and dog, into recovery rates of their body elements and list them in Table 6.4. For sheep/goats and horses, I list the MNE of each element in Appendix C: Table C.1 because their values are too low for drawing any conclusion. Since teeth are relatively diagnostic and are the most durable parts of the skeleton, loose teeth were not incorporated into the calculation of MNE. For cattle, the proximal radius, proximal metacarpals, and distal metatarsals appear to be well represented in the body-part assemblage as their recovery rates are higher than 50%. Skull and mandibles are also well represented element in the assemblage, but these cranial parts discovered from the site are very fragmentary. Studies of the differential survival of body parts (Binford 1980, 1981; Lyman 1984) show that mandible and maxilla are usually two of the best surviving body parts. Atlas and axis also survive destructive forces well and have a higher percentage of survival than any of the other vertebrae. In the Taicheng assemblage of cattle, these two elements, however, are poorly represented. Also, cattle vertebrae and ribs are not surprisingly underrepresented because they are difficult to identify down to species level. In general, the recovery rates of axial bones after the cranial part are relatively low; the highest is the sacrum with the recovery rate of just 44%, but the low recovery rates of cranial and axial bones are unlikely resulted only from the poor preservation of bones.

One remarkable pattern in the assemblage is related to phalanx and accessory bones (e.g., carpals and tarsals). These elements were found with very low recovery rates. In addition, the front limbs appear to be better represented than the rear limbs. Proximal radius has the highest recovery rate in the assemblage, while femur and tibia were found with low recovery rates at about 10~20%. In order to evaluate the potential biases caused by post-depositional processes, I need to examine the recovery rates of other parts that can survive destructive forces well (e.g., scapula, pelvis, distal humerus and tibia, and proximal radius) at the same time. According to Binford (1981:281-237), the ratio of the proximal and distal portions of the humerus is particularly indicative of the intensity of post-depositional destruction because the distal humerus survives much better than the proximal ones. If these elements in general have high recovery rates, or the distal humerus is more representative than the proximal part, the assemblage may have been significantly shaped by post-depositional forces.

But in the body-part assemblage, except proximal radius, other elements that can survive destructive forces well were not all well represented. Besides, the recovery rates of the proximal and distal metapodials are relatively close to each other with relatively high recovery rates. For the lower limbs, the distal metacarpal usually has a greater survival rate, and the phalanx only have a survival rate about half that of the proximal metapodials (Landon 1996). But in the Taicheng assemblage, the recovery rates of phalanx are only 11.1% (1st phalange) and 5.6% (2nd and 3rd phalange), which are significantly lower than the recovery rates of all metapodials. The low recovery rate of phalanx might therefore not be entirely attributed to the issue of taphonomic process. Furthermore, although the recovery rate of the distal humerus is higher than the proximal one, the MNE of these two parts are both generally low; only a total of three pieces were found. Very likely, the high recovery rates of some elements from Taicheng were not completely subject to the biases of preservation; market preference, consideration of transportation, and taphonomic forces all contributed to the mechanism.

According to the cattle body-part assemblage, the front limbs seemed to have been the preferred cut; the recovery rates of humerus and radius are much higher represented than those of femur and tibia. If we take all metapodial recovery rates into consideration, the less meaty part of limb bones (lower limb bones) are generally better represented. Since both proximal and distal metapodials have high recovery rates, this preference is not solely subject to bone survivability.

Dog represents the second largest NISP value in the assemblage. With an MNI of six individuals, does are more abundant than cattle and pigs. But unlike cattle, the most dominant elements in the assemblage of dogs are the skull (calculated based on maxilla) and mandible. The high recovery rates of these elements are not surprising because they can survive destructive forces well and are very diagnostic. Following the cranial parts, femurs are also well represented with a recovery rate over 50%. The representation of the forelimbs is slightly lower; the recovery rate of the distal humerus and proximal radius both are only 33%. Also, the lower limb bones (e.g., metapodials and phalanx) are underrepresented; the recovery rates of these elements are lower than 10%. Accessory and post-cranial axial bones are particularly absent in the assemblage. The patterns in body elements indicate that carcasses of dogs might have been brought to the site as butchered meat cuts. But compared to cattle, the selection of dog meat seems to include a wider range of elements.

The NISP of pig bones makes up about 30% of the total identified samples. Significant differences are present in the proportional representation of pig forelimbs vis-à-vis cattle and dog. The post-cranial bones are remarkably underrepresented in comparison with cranial parts. Limb bones and other axial bones as well were barely found in the pig assemblage. Among all limb bones, the proximal unla has the highest recovery rate, but it is just 25%. Also, no femur, tibia, and accessory bones were found. This pattern is quite different from the collections of cattle and dogs. For these two taxa, the recovery rates of limbs bones are much higher in the body-part assemblages. But as Landon (2005) pointed out, the marked difference between the cranial and post-cranial recovery rates in pig bones is often related to destructive forces. If the majority of pigs was very young, their fragile limb bones would not survive as well as their cranial parts.

Thus, the head-dominant pattern in pig assemblages does not necessarily mean other portions were not brought to or consumed at the site. As I will discuss in the next section, this idea, in fact, is substituted by the evidence of teeth eruption. Most of the mandibles and maxilla with teeth from the site show that pigs were slaughtered at young ages between 12~18 months old. The explanation of the pig body-part assemblage in this case needs to consider these age and bone survivalbilty concerns.

In comparison with other mammals mentioned above, sheep/goat bones were not well represented in faunal records (Appendix C: Table C.1). For sheep/goats, the scapulae and mandible represent the highest MNE in the assemblage. Other axial parts (i.e., pelvis) are not well represented. Also, accessory bones are missing in the assemblage. Both metatarsal and metacarpal bones in the assemblage are also under-represented. Similar to the pig, elements associated with the appendicular bones are poorly represented in the assemblage of sheep/goats. This pheonomenon might be related to two issues. First, most elements of pig and sheep/goat that were brought to the site might have been just bony and low-yield portions. The second issue may be relevant to preservation and survival rate of bones. If these sheep/goats were killed at a very young age, their limb bones and other elements might not survive destructive forces well and, eventually, could not be discovered. The pattern of sheep/goat is also different from horse elements, and merits further explanation. Certain numbers of horse elements were found, and the majority are limb bones. This pattern is distinctive from that of sheep/goats and pigs. Except two teeth, no horse cranial part has been found. Other elements that were found are appendicular parts. Although horse bones were found in very low NISP number, their body-part assemblage seems to reflect a consumption preference different from medium-sized mammals.

Since certain numbers of the bones can only be identified to the size of mammals, it is necessary to evaluate if these fragments include large numbers of elements that are difficult to identify (e.g., ribs and vertebrae) instead of shaft fragments. In the case of large mammal fragments, the NISP of ribs and vertebrae are 21 and 5 respectively, and the two types of fragments account for about 50% of the total NISP. Even if we assume that all these samples belong to cattle and use the MNI of cattle to calculate the recovery rate of these two elements, the recovery rates will be just 18% and 4.7% respectively. Also, since ribs and vertebrae tend to be fragile, and their fragments would boost up the numbers of NISP, these two rates undoubtedly are overestimated; the actual recovery rate of these elements must be much lower. In the category of medium size mammals, the NISP values of ribs and vertebrates are 26 and 3 respectively with a total weight of 55 g. If we take the total MNI of pigs, sheep/goat, and dogs together—which is 14—to calculate the recovery rate, the results are just 4.4% and 0.5%. Since atlas and axis were underrepresented in the assemblages of all livestock, the two lines of evidence strongly suggest the post-cranial axial parts of both large and medium size mammals only contributed a light portion of meat to workers' daily diet.

Patterns in body-part assemblages explicitly suggest the consumption preferences of different species vary to a certain extent. For cattle, one dominant feature of the recovery pattern was the over-representation of the less meaty parts of limbs versus rich meaty parts. In general, the front limbs show more favorable numbers than the hind limbs. Furthermore, axial parts are not as frequently found in the assemblage as other appendicular parts. Inherent in all of these possible explanations is the idea that workers might rarely consume meaty portions like loin associated with the axial part, and might rely more on less meaty portions for making bone soup. In short, these patterns indicate that the meatier portions or more meat-bearing elements might have been processed intensively before deposition or traded, never entering this archaeological assemblages (Landon 2005). Also, the underrepresentation of accessory bones in the urban assemblage indicates carcasses that were brought to the site are likely to be small-sized "retail cuts" of meat.

For middle size mammals (sheep/goats, pigs, and dogs), evidence also shows that they were neither butchered at the site nor brought to the site whole. Consumption patterns differed between the three species. For instance, the recovery rates of pig limb-bones (both the fore and hind limbs) are surprisingly low in comparison with those of skull and mandible. Similarly, for sheep/goat, the appendicular parts have poor representation. For dogs, the body-part assemblage is slightly different in the sense that appendicular parts are better represented, indicating a wider variety of body parts might have been consumed. But across the assemblages of the three species, the post-cranial part of axial skeleton (i.e., ribs and vertebrae) and lower limb bones are both significantly under-represented. In the section below, I will discuss taphonomic factors such as weathering, burning, and carnivore chewing, as well as the selection of slaughtering age and the impacts of kill-off pattern in the survival of faunal remains. In juxtaposition with these lines of evidence, I can better evaluate not only the livestock raising system in the Han period but also the post-depositional factors in the transforming the faunal remains.

6.4. Taphonomy and Kill-off Pattern

Many factors can shape the taxonomic and body-part representation in archaeological contexts between the time bones are first deposited and the time they are analyzed. Among them, taphonomy is always the most important one. Any meaningful interpretation of data has to incorporate traces of weathering, chewing marks, burning identified from the Taicheng assemblage and recorded during analysis in order to investigate to what extent the patterns observed are related to these issues (Table 6.5).

Table 6.5 Frequency of taphonomic feature and butchery marks for major taxa at the Taicheng foundry

	Cattle NISP		Pig NISP		Dog NISP		Caprine NISP		Horse NISP	
Taphonomy/modification	count	%	count	%	count	%	count	%	count	%
Weathering a	11	11.3	4	8.2	1	1.2	3	8.1	2	10.5
Burning b	7	7.2	4	8.2	26	35.6	3	8.1	1	5.3
carnivore gnawed	18	18.6	3	6.1	1	1.2	1	2.7	2	10.5
rodent gnawed	1	1.0	0	0.0	0	0.0	0	0.0	1	5.3
Butchered c	23	23.7	4	8.2	8	10.1	1	2.7	3	15.7

a criteria see (Behrensmeyer 1978)
b criteria see (Buikstra and Swegle 1989)
c criteria see (Lyman 2005; Shipman and Rose 1983)

For weathering signs, only 28 specimens show various degrees of weathering. These signs range from one to two (slightly weathered) according to Behrensmeyer's classification (1978). These specimens represent about 5% of the total NISP value (Table 6.5) and include cattle, pigs, and sheep/goats. The body-part assemblages showing weathering signs do not reflect a clear difference between the cranial and post-cranial elements. In an urban context, scavenging carnivores could be an important post-depositional agent for exposed bones (Schiffer 1987). Among the 37 elements showing signs of carnivore chewing, which represent about 10% of the total identified samples, one-fourth of them show signs of weathering as well. One possible reason is that some discarded bone remains were exposed in open air for a certain period, which eventually attracted dogs coming to scavenge. Also, such bones could have been used to feed dogs that were raised at the site as watchdogs. It is interesting to note that cattle and horse bones have higher rates showing signs of weathering and carnivore chewing than pigs, dogs, and sheep/goats. Since bones of large mammals survive better, evidence on cattle and horse bones have more chances to preserve in archaeological contexts. But in general, the numbers of bones that were exposed are not very high in the assemblage. These two factors should not have played a significant role in biasing and skewing the entire recovery pattern of these mammal remains.

About 20% of identified samples represent signs of burning to various degrees (Table 6.5), but the modification seems to be moderate as bones with signs above level three are relatively few. Over 30% of dog bones show signs of burning, which is significantly higher than that in the other four species. The high percentage of dog bones showing signs of burning might indicate how dog meat was prepared or consumed. Perhaps dog meat was more frequently grilled while other types of meat were cooked in a different way[86]. But as the percentage of bones with burning signs in cattle, pig, and caprine bones is relatively low, the impacts by burning on these species might be very limited in skewing their body-part assemblages.

A total of 47 specimens (Appendix C: Table C.2) show traces of butchery marks, which accounts for about 10% of the total identifiable specimens. According to the depth and profile, these butchery marks include scrapes, cuts, shear marks, and chop marks left by knives and axes. The identification of tool marks is based on previous studies of cut marks on bones (Crader 1990; Lemke 2013; Lyman 1977, 2005; McKee 1987). Scrape and cut marks refer to the butchery marks with narrow and shallow v-shaped profile for removing or cutting off meat. The difference is that the former is shallower while the latter one left deeper marks. Chop marks are associated with wide and deep cutting profiles which would remove certain fragments from surfaces for dividing the same part into several portions. Chopping (e.g., splitting a metapodial into two

[86] Alternatively, the high frequency of burning signs might also be related to the fact the consumption was adjacent to the hearth, and therefore bones were discarded into the hearth.

halves) would also leave straight and smooth edges, or shear marks, on the suface (Crader 1990; Landon 1996; Reitz and Wing 2008). Cut marks are found on specimens across all major species. Also, based on the frequencies of the other three types of marks, it is difficult to determine if they show any taxonomic variation.

These four types of marks might be associated with different procedures of meat processing. For cattle, there are six cases showing shear marks that divided the shaft of the metatarsal vertically through the center slightly below the midpoint for marrow extraction. Two cases of scrape marks—which are small parallel cut marks—were found on one metatarsal and one metacarpal, suggestive of meat fileting. Eight cases of cut marks were found on various elements including the spine of a vertebra and the distal end of a humerus, which are related to the removing meat of from bones. In addition, chop marks were also found on the lateral side of a large mammal rib bone—very likely a cattle rib, reflecting the division of rib slabs into several sections by chopping.

Long and thin scrape marks were also found on two pieces of pig mandibles. For instance, the example H16g27 shows scraping marks on the lateral face of the bottom of the ascending ramus. These butchery marks were left by the scraping and consuming of the jowl or cheek meat. Chop marks also appear on the frontal end of cattle and dog mandibles, indicating the marrow was extracted. Although most of the butchery marks are associated with cutting meat off the bones or extracting marrow, at least one is clearly a result of dismembering of the carcasses. Example H31g2, which is a cattle calcaneus, shows cut marks near the superior end of the anterior side. This cutting usually is used to create an opening between the tibia and the tendons coming off the calcaneus for inserting a gambrel to hang the animal (Landon 1996).

In the Taicheng assemblage, the preservation of butchery marks seems to be related to the completeness and size of bones. 23.7% (N=23) of cattle and 15.7% (N=3) of horse bones show at least one type of butchery mark, but for pig, sheep/goat, and dog bones, each species has only 2~10% of specimens with butchery marks. Cattle and horse bones are more robust and tend to generate larger size fragments. The identification of butchery marks may have been biased by the fracturing degree of bones and the size of fragments. Furthermore, if meat was obtained and cooked as relatively large and complete cuts, their butchery marks might not be found as frequently as those meat cuts that were professionally butchered into small portions. Future study may try to collect more quantified data to show if the frequency of butchery marks is varies in relation to the size of livestock or even the size of fragments.

Table 6.6 Epiphyseal fusion of cattle and dogs

Cattle (count)

age of fusion	**body part**	**u**	**e**	**f**
7-10 months	scapula			2
	acetabulum			3
12-18 months	distal humerus	1		2
	proximal radius			6
18 months	distal first phalanx			4
	distal second phalanx			2
24-30 months	distal metacarpal	1		4
	distal tibia			2
27-36 months	distal metatarsal			5
36-42 months	calcaneum			2
42 months	proximal femur			
42-48 months	proximal humerus			
	distal radius			3
	ulna	1		
	distal femur	1		
	proximal tibia			
	Total	4	0	35

Dogs (count)

age of fusion	**body part**	**u**	**e**	**f**
6 months	Pelvis			3
6-7 months	Scapula	1		
7 months	proximal second phalanx			
8 months	distal metacarpal			3
8-9 months	distal humerus			3
9-10 months	ulna olecranon	2		2
10 months	distal metatarsal			1
11-12 months	ulna distal			3
	proximal radius			3
	distal radius			4
13-16 months	distal tibia	2		2
	Calcaneus			
15 months	proximal humerus		2	
	distal fibula			1
15-18 months	proximal fibula			
1.5 years	Proximal femur	3		1
	distal femur	4		1
	Proximal tibia	1		2
		13	2	29

u : unfused; e : epiphyseal lines; f : fused

In sum, except for the percentage of burning signs on dog bones being relatively high, cattle, sheep/goats, and pigs are onliy subject to a moderate degree of weathering, burning, and animal gnawing. For pigs, dogs, and sheep/goat, butchery marks are also only occasionally found. At this stage, it seems reliable to suggest that the taxonomic and body-part representation reflect deliberate human actions rather than the result of taphonomical factors.

As I alluded to previously, the kill-off patterns can help evaluate the impacts of destructive forces on skewing faunal assemblages. Since the survival of an element is directly related to its hardness, the epiphyses of bones that fused earlier in life would survive destructive forces than those fuse later in life. Consequently, remains of young animals generally cannot survive as well as adult animals of the same species (Landon 1997:47). In addition, the estimation of slaughtering ages can hint at the exploitation strategies and production system of livestock.

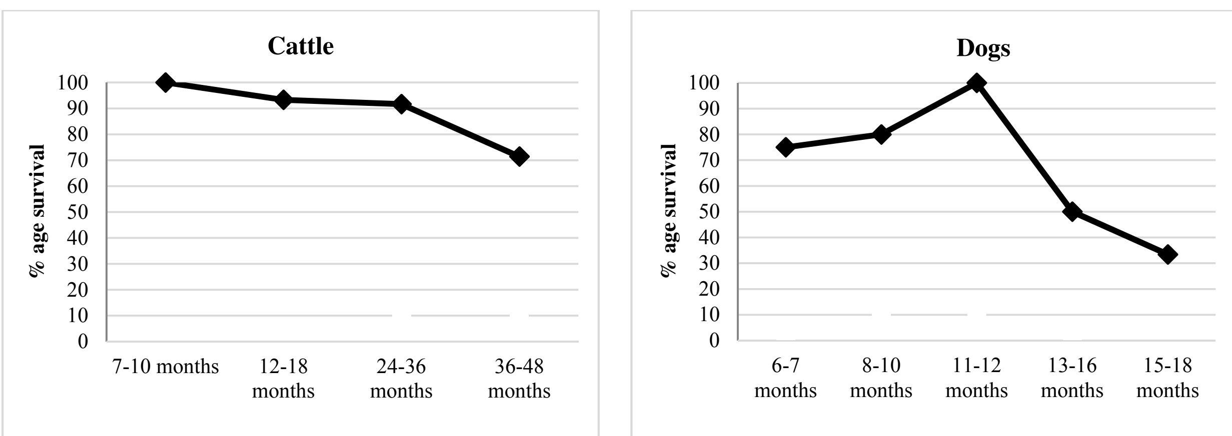


Figure 6.2 Kill-off patterns of cattle and dogs based on epiphyseal fusion

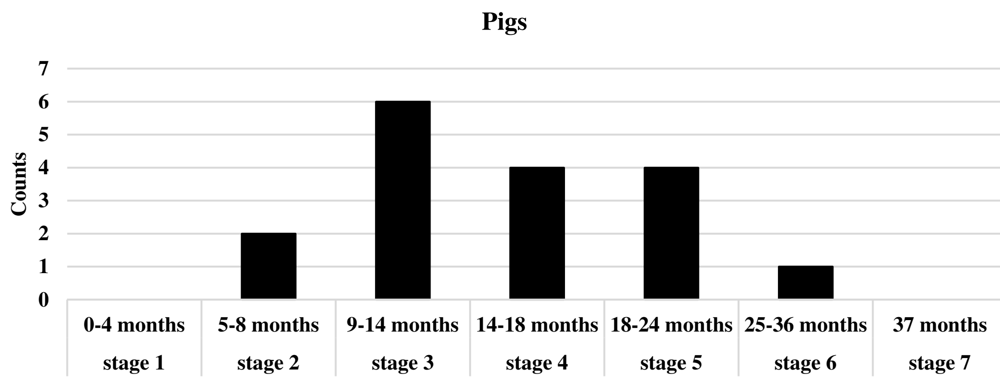


Figure 6.3 Wear stage of teeth in pig tooth-rows and loose teeth

Slaughtering ages are usually calculated based on epiphyseal fusion and teeth wear. Available data about the teeth-wear degree of cattle, however, are too few for drawing any reliable conclusion in this case study. I only examine the epiphyseal fusion to reconstruct the age-of-death of cattle. In contrast, for pigs I estimate the slaughtering ages based on the degree of teeth wear because limb bones are too few. In Table 6.6, I list the counts of epiphyseal fusion of different elements to identify the slaughtering patterns of cattle and dogs (Figure 6.2). I also list the counts of different stages of teeth eruption and wear-degree in Figure 6.3, which is based on previous research on pigs conducted by Ma Xiaolin (2008). According to the epiphyseal fusion, the majority of cattle consumed at Taicheng was of the old age group; only about 20% were killed younger than 42 months. As cattle consumed by Taicheng workers in general was old or worn-out stock, they would have yielded meat that is tough and considered undesirable (Bowen 1998), and might have been raised primarily for other purposes (e.g., traction or drafting) instead of specialized meat production.

The slaughtering ages of pigs and dogs present a distinctively different pattern. Table 6.6 shows that most dogs were killed at a young age before turning into adolescents at 1.5 years old. Similarly, in Figure 6.3, about 70% of pigs fall within the range of slaughtering ages between 12 and 24 months old[87]. In particular, the data witness a peak at stage III corresponding to 9-14 months old. No data indicate any pig was killed older than 3 years old. Without the employment of any fertilizer, the best killing time for pigs to maximize production would fall within the range between 1.5 and 2 years old (Li 2011), which exactly matches the killing-off pattern of pigs at Taicheng. It seems very likely these pigs and dogs were raised specifically for the production of meat. Overall, the slaughtering ages indicate these livestock might have come from different production systems: cattle might have been raised for traction or drafting, whereas pigs and dogs might have been raised for maximizing meat production and killed before turning into adolescents.

Another line of evidence supporting the high survival rate of cattle comes from pathology. A total of ten cases with various pathologies have been found. Among them, eight cases are cattle, and the other two belong to a horse and dog bone. In the case of the dog, a tibia had a poorly healed trauma. Eight cattle and one horse bones displayed arthropathy, probably resulting from long-term traction such as ploughing, pulling carts, or pulling the mill for grounding (Bartosiewicz, et al. 1997; Groot 2005). As mentioned earlier, excavated texts mention that the local government would own and manage certain numbers of oxen and horses for farming or public transportation. Local official needed to sell out the meat, bone, skins, and almost every part of a livestock that was sellable in order to collect the cash that the livestock has valued for if it was too old, sick, or even dead[88]. One source of these old-age cattle was probably from this type of government-owned livestock. If so, this evidence supports my major argument here that these iron workers obtained meat primarily through a meat market system.

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[87] For the estimation of ages see data in Appendix C: Table C.3.

[88] *Shuihudi*, "Statutes on Stables and Parks", trans. Hulsewe 1985:A9, p.27

To combine all these lines of evidence together, it is clear the faunal remains from the foundry were definitely subject to various taphonomical processes. Part of the faunal remains had been exposed in open-air before being deposited entirely. Although the number is not significant, this factor still would have contributed to the high fragmentation degree of medium size mammals and skewered the numbers of identifiable specimens. Carnivores, either domestic dogs raised by workers themselves or scavenging dogs attracted by bones or left-overs of exposed food, transformed faunal records after human consumption. Also, the burning of bones, mostly dog bones, also increased the degree of bone fracture among medium sized mammals while decreasing their identifiability. In addition, butchery marks also confirm that cutting off meat from bones, dividing the carcass into portions of different sizes, and marrow extraction further contribute to the fragmentation degree of bones and skewed[89] the body-parts presentation. But none of these factors mentioned above did generate a substantial and thorough transformation in the assemblages.

After taking taphonomy and age into consideration, the study of faunal remains clearly supports the view that the operation of Taicheng involved exchange and interaction with a specialized meat production and market system. The beef and horse meat consumed by iron workers was probably the small retail meat cuts of old livestock that were sold at the meat market. Pork and dog meat was also relatively small retail meat cuts, but these two species were raised by a system that intended to maximize the meat production. Even though pigs and dogs would have been raised just at the backyard instead of a centralized farm by farmers or even by iron workers themselves, the livestock was collected by a market system first and processed by

[89] Even though most of the pigs were very young individuals, it is still difficult to explain why the majority of limb bones is missing in the assemblage. Also, as I will point out in the next section, only using wear-degree might lead us to underestimate the killing-ages of pigs.

others. The body-part assemblages also suggest the iron foundry was separated from the place where butchering or food processing took place. Iron workers at Taicheng, therefore, relied on their neighbors or other members to procure the meat that they consumed. There is no evidence that workers raised the meat or livestock. In this regard, the supply of meat to the site is very similar to the food chain that characterized urban centers in other archaeological case studies. The patterns in faunal remains seem to fulfill the major requirement of being a full-time specialized workshop.

6.5 A Comparative Case Study of the Iron Foundry Diet

In this section, I focus on a comparative analysis of faunal remains from another iron foundry during the Late Bronze Age in the capital walled town of the Zheng and Han states (Luo, et al. 2006) in Henan province. Even though many patterns in the Taicheng faunal remains look similar to an urban food-chain system, it is still impossible to judge the degree of specialization based on faunal remains from one case study. For instance, if some dogs and pigs were raised and then consumed by workers, the iron foundry still could not be viewed as a full-time specialized iron workshop. One can even argue that the iron workers at Taicheng would have owned certain numbers of cattle for transportation and then consumed them when they were too old. If so, this can also explain why cattle bones generate the highest NISP in the assemblage. A comparative study is necessary to elucidate to what extent the consumption at Taicheng was similar to or different from an urban workshop or residential section where large-scale pig or dog raising was unlikely to take place.

As I explained in Chapter 4, Taicheng is situated inside a local administrative center, but the degree of urbanization of these centers is unclear and difficult to determine. Ideally, the faunal assemblage from other contemporary urban centers and rural districts would help to address these issues. But the ancient diet during the Late Bronze Age (Western Zhou) and Early Imperial period, unfortunately, are still poorly understood through zooarchaeological analyses. Especially during the Western Han period, up until now we only have preliminary reports on remains from a small section of the capital (Hu, et al. 2006) in this region. This dataset is by no means large enough for a quantitative comparison. Although diet and meat consumption in the daily life of this period have been addressed in several scholarly works focusing on transmitted and excavated texts (Hayashi 1975; Sterckx 2011), the role that archaeology has played in the study of diet is still limited, and therefore cannot help integrate the archaeological case study into its larger social context.

But thanks to the publication of the site report Zhonghang (Henan 2006), this study on an Warring-States iron foundry has an invaluable comparable dataset which can enlarge our understanding of patterns represented by the data. The Zhonghang iron foundry is located in the capital walled town of the Zheng and Han states in present-day Xinzheng City, Henan. The capital first belonged to the Zheng state during the Springs and Autumns period and was later, in 375 BCE, conquered and occupied by the Han state, one of the three successor Jin states after the partition of the Jin state by rival families. The walled town is trapezoidal in form and consists of two sectors divided by a wall. Situated inside the larger compartment, a cast iron foundry, roughly dating between 375 and 230 BCE, was established directly above a bronze foundry and a sacrificial venue dating to the Springs and Autumns period. Most importantly, this iron foundry has been excavated intensively, and all zooarchaeological results have been systematically published both in the full site report and online database[90]. In addition, the site is situated within an unquestionable urban center and primarily produced iron agricultural tools. A comparison between the two cases is promising to further interpret data from Taicheng and the diet of iron workers, even though Zhonghang is much larger than Taicheng in scale.

Table 6.7 shows the NISP values of all identified species at Zhonghang. The taxonomic assemblage at Zhonghang also consists of cattle, pigs, sheep/goats, dogs, and horses, very similar to Taicheng. The major difference between the two cases in the taxonomic assemblage lies in the fact that pigs seem to have play a more significant role in their diet; the percentage of pigs (20.1%) significantly outnumbers other species except cattle in Zhonghang. In addition, deer and horse bones account for about 5.9% and 4.6% the total NISP respectively—these values are even higher than those of sheep/goats (4%) and dogs (3.8%). At Zhonghang, dog bones are only about 6% of the total NISP in the assemblage, but workers at Taicheng appeared to rely more heavily on dog meat as dog bones account for about 24% of the total NISP.

Table 6.7 Taxonomic representation at the Zhonghang foundry

		NISP	
		Count	%
Bos taurus	Cattle	562	28.4
Sus scrofa	Pig	398	20.1
Ovis aries/Capra hicus	Sheep/goat	78	4.0
Canis sp.	Dog	75	3.8
Equus caballus	Horse	117	5.9
Odocoileus virginianus	Deer	90	4.6
Unidentified clam		3	0.2
Unidentified birds		7	0.4
Large mammals		324	16.3
Mammals		319	16.2
Unidentified carnivores		4	0.2
Total		1977	100

[90] The database can be downloaded from http://www.archaeology.net.cn/html/cn/xueshuziliao/kaogushujuku/dongwukaoguziliaoku/2013/1025/31728.html

Other identified species in the assemblage dating to the Warring States period include birds, mussels, and carnivores in general. In the assemblage, there are only two specimens identified as bird, but this discrepancy is very likely related to the recovery and collection method. Without any screening of soil samples, smaller size bones, such as bird and fish remains, might not have been collected during excavation[91]. In the database, large numbers of cranial, vertebrae, ribs, and long bone shaft fragments were identified only to the size categories (large mammals vs. mammals). Given the predominance of domestic animals in the assemblages, the majority of them very likely are cattle, pigs, sheep/goats, and deer bones.

Body-part assemblages of Zhonghang can further disclose the dietary difference between these two communities. Figure 6.4 and 6.5 show comparisons of body-part recovery rates between the two sites (for data of body-part assemblages from Zhonghang see Appendix C: Table C.4). In Figure 6.5, the most dominant elements of cattle bones belong to the cranial part, followed by humerus, scapulae, and tibia. The cranial part, even not calculating loose teeth, appears to be more dominant in the assemblage than the case at Taicheng. In addition, it is hard to tell if the forelimbs were more preferable than the hind limbs because the numbers of tibia and humerus are relatively equivalent. Carpals are missing in the identification, but it might have resulted from the lack of collection of small bone remains. Other accessory bones like calcaneus, talus and phalanges are better represented in the assemblage than in the Taicheng assemblage. In comparison with Taicheng, axial, atlas, and upper limb bones (e.g., humeri and femurs) in this

[91] Even though all identification results were fully published both in the site report and on-line database, the report has not mentioned specifically the collection method of samples. This makes it hard to evaluate to which extent the result would be skewed by the data collection method.

case are better represented. Also, the metapodials do not seem to be as well represented as in the case at Taicheng.

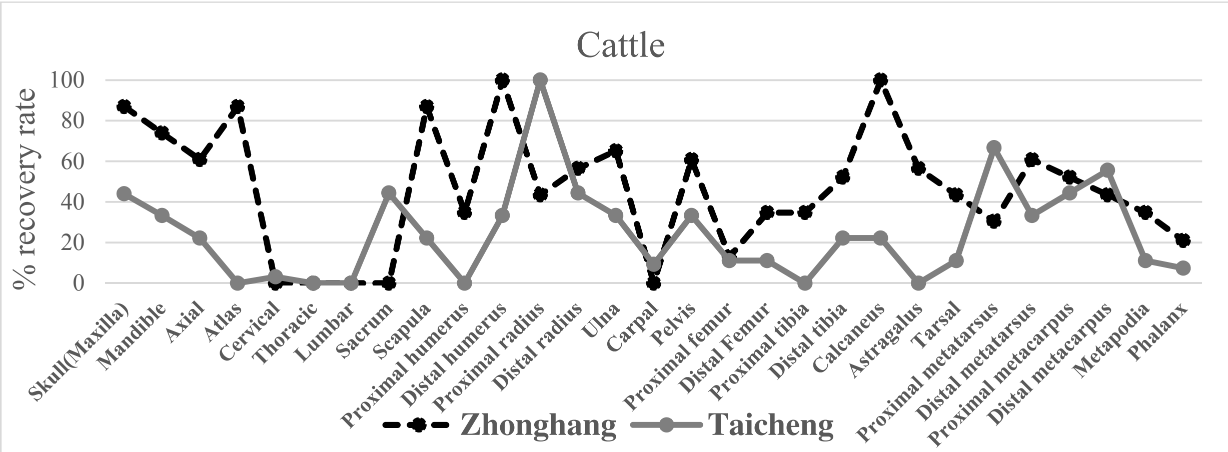


Figure 6.4 Recovery rates of cattle elements from Zhonghang and Taicheng

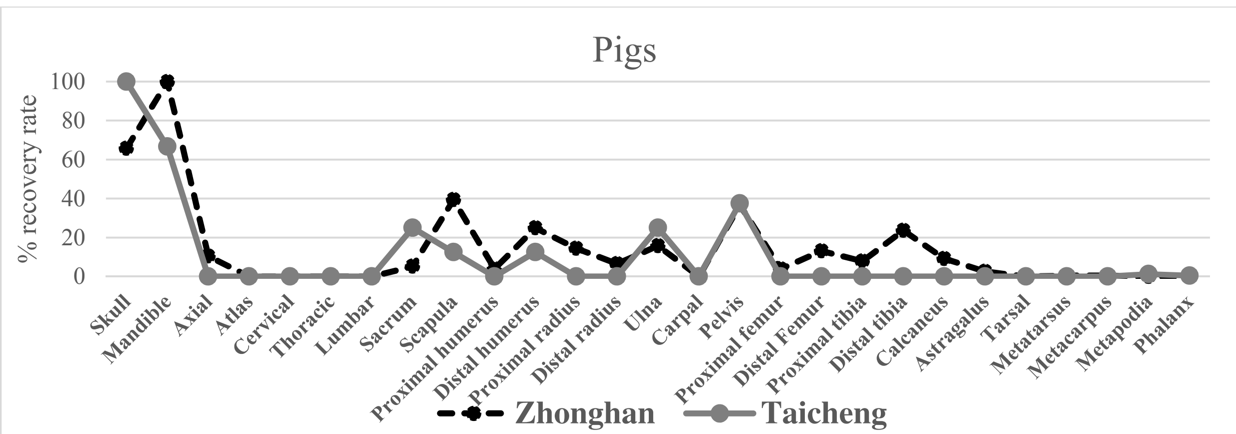


Figure 6.5 Recovery rates of pig elements from Zhonghang and Taicheng

In the body-part assemblage of pigs, it is of interest to note the similarities between these two cases. First, the skull and mandible are similarly the most dominant parts. Second, appendicular bones or limb bones are both significantly underrepresented. Although meaty elements, such as humeri and femurs, were more frequently identified in the Zhonghang assemblage with recovery rate of about 20%, the lower limbs (i.e. metapodials and phalanges) and accessory bones are significantly underrepresented. Both cases demonstrate a prominent discrepancy between cranial and post-cranial elements.

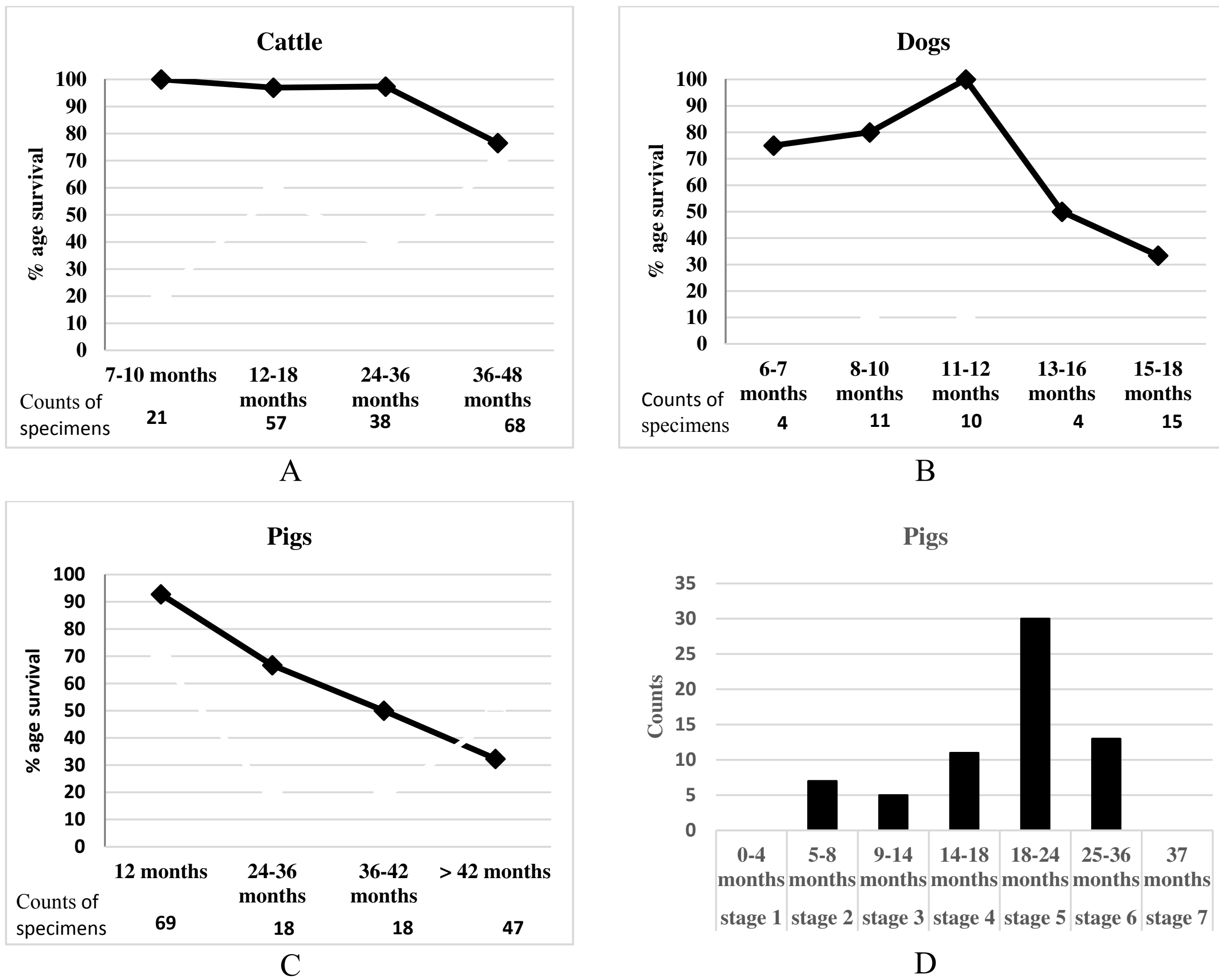


Figure 6.6 Kill-off patterns of cattle, dogs, and pigs based on epiphyseal fusion and wear stage of teeth in pig tooth-rows and loose teeth

a. Kill-off pattern of Cattle based on Fusion Stages of Limb Bones
b. Kill-off pattern of Dogs based on Fusion Stages of Limb Bones
c. Kill-off pattern of Pigs based on Fusion Stages of Limb Bones
d. Slaughtering Age of Pigs based on Eruption and Wear Stages of Teeth in Toothrows and Loose Teeth

For sheep/goats at Zhonghang, the cranium, scapula, distal humerus all have recovery rates of over 50 percent. In addition, the discovery rate of distal tibia and proximal metatarsals are all above 30 percent. These parts are more likely to survive against destructive forces. Deer bones comprise about 10% in the assemblages of the total NISP. Most deer bones were only identified to size category, except *Cervus nippon*. The body part assemblage shows that limb bones and post-cranial portions are better represented than cranial portions in the assemblage of deer bones. Perhaps the consumption of deer meat concentrated more on certain elements in comparison with other species. Horse elements include both cranial and postcranial portions. But phalanx, especially the third phalange, are the most overwhelmingly dominant element followed by scapula; the numbers of other elements represented in the assemblage are very limited. For unknown reason, the lower part of horse limb bones were transported to the site, perhaps for making bone soup, instead of discarded in butchering area.

It is noteworthy that the age profiles in the case of Zhonghang[92] also demonstrate patterns identical to the case of Taicheng (Figure 6.6). For the age profile of cattle, the Zhonghang case shows that remarkable portions of cattle were killed at relatively old ages. According to the epiphysis fusion of limb bones, more than 90% of the cattle consumed by workers were not killed until two years old. The survival rates of three and four year old cattle even exceeded 70%, indicating cattle husbandry was not intended for a specialized meat production. Very likely, the cattle consumed at both Zhonghang and Taicheng might be raised for drafting and killed when they died of natural cases.

Comparison between degree of teeth wear and epiphyseal fusions generate a somewhat confusing image regarding the slaughtering ages of pigs at Zhonghang (Figure 6.6). According to the degree of wear of the toothrow, the prime slaughtering ages of pigs at Zhonghang are between 18 and 24 months. In addition, there are 16% and 20% of pigs in the assemblage that were slaughtered belonging to the age group of 14-18 months and 25-36 months. Only about 7%

[92] For the original data, see Appendix C: Table C.5; Table C.6.

of the remains belong to very young pigs killed during their first year. No evidence shows that pigs were slaughtered after 3-year-old.

But the information presented by fusion data seems to depict a different picture of slaughter ages. Unfused bones show that only about 33% of pigs were killed before 2-year-old. The assemblage also contains bones that are fused later than 42 months, suggesting that some pigs were skilled at a relatively old age. As I mentioned earlier, taphonomic impacts on the assemblage must be taken into consideration before any meaningful conclusion is drawn. The assemblage might have been subjected to taphonomic destruction leading to the underrepresentation of juvenile pigs in the assemblage. Yet, even taking post-depositional process affecting young juvenile pigs into consideration, this still cannot compellingly explain the large numbers of the bones that fused at older ages. Possibly, the age estimation of wear degree does not correspond well with actual data. Perhaps given the difference in food or living environment, the wear rate of pig teeth during the Warring States China (or perhaps even the Han China) was slightly lower than the standards (Ma 2008) that I adopt here, which could lead to an underestimation of slaughtering ages of archaeological specimens.

According to the epiphyseal lines, the pattern of slaughtering ages for sheep/goats does not appear to be as clear-cut as cattle and pigs. The assemblage contains certain numbers of young and old individuals, even though 50% of individuals were slaughtered before 3-year-old. This kill-off pattern implies that the butchering industry might not be intensified for meat production by slaughtering more young sheep/goats. But for dogs, the pattern in bone epiphyseal fusion seems to be consistent with data from Taicheng. In the Zhonghang assemblage, most dogs were killed between one and 1.5 years of age.

To summarize, there are several common patterns in the two cases. First, in terms of the taxonomic abundance, the majority of species found at these two sites are all domestic livestock; animals that would be obtained through hunting, or wild animals, only occupy a very small percentage in the assemblages. Deer might be an exception, but they were sometimes raised and kept in circumscribed areas for elite or royal hunting at least since the Western Zhou (Huang 2000). It is therefore difficult to say for certain whether the remains of deer were procured through the hunting subsistence of “wild animals’. Second, at Zhonghang, the lower part of cattle limb bones (everything below the humerus ad femur) and certain accessory bones was relatively more dominant in the assemblage than the case of Taicheng, indicating the size of meat cuts that were brought to the Warring States foundry was different from the case in the Han period. But in general, as lower limb bones like phalanx were not well represented in the assemblages of major livestock, the slaughtering did not take place inside or even adjacent to the foundry. Third, the killing-off patterns of cattle and pigs in these two cases unmistakably point to a specialized husbandry, including meat production. All patterns perfectly correspond to the urban context in which the Zhonghang iron foundry was situated.

The conclusion that the Zhonghang faunal remains match the expectations of the urban food chain should come as no surprise. But what is more significant in the patterns is that the faunal records from Taicheng are similar to Zhonghang in terms of the taxa, body-part representation, and kill-off patterns. If we view Zhonghang as a high-intensity foundry—i.e., a workshop that completely relied on the meat market to obtain and purchase meat produced by others—that is situated in an urban center and specialized in production, Taicheng should also be categorized as the same type of workshops according to the evidence of faunal remains, even it is in a county-level setting.

In juxtaposition with textual records, archaeological evidence also helps investigate the potential social and economic status of iron workers. Given the relatively high price of meat in relation to workers' wages per day, the iron workers at Taicheng were not supposed to afford the types of meat (beef, pork, and mutton) identified based on bone remains identified. Chicken or poultry meat would be more frequently consumed in commoners' diet because of its affordable price. Archaeologically, chicken bones would have been the most common taxa from a foundry site in which the majority of laborers were hired workers. But the faunal assemblages from the two cases of iron foundry sites were different from these hypotheses. Instead, cattle and pig remains dominated the assemblage. Very likely the majority of workers at both Zhonghang and Taicheng were not the type of convict or corvée laborers mentioned in the texts of the Han period. Even if most of them were hired laborers, archaeological evidence suggests that either their wages may have been higher than the average, or better food may have been provided as by the owners or the government.

Some differences were prominent between the two cases, but they are relevant more to the environment of these two foundries than to the status differentiation between different groups of iron workers. It appears that larger size of meat cuts might be the primary form of meat resources at Zhonghang. Also, the consumption of meat focused more on a wider range of beef and pork. In addition, pigs and deer played a more important role in the dietary system at Zhonghang. As Zhonghang was much larger in size, and presumably hired more iron workers than Taicheng, more meat was logistically required to support a larger cohort of ironwork community. For this reason, iron workers at Zhonghang might rely more heavily on relatively cheaper pork and richer meat-yielding portions of beef, whereas the Taicheng foundry collected and relied on less meaty portions, smaller size meat cuts, and smaller size livestock. Furthermore, since Taicheng was not situated inside a complex urban center, workers might have fewer options of meat at the market. Taking one step further. They might not even have the same amount of meat per day as workers in an urban center. In short, it is without any doubt that iron workers at the Taicheng foundry relied on a specialized meat market system and became full-time specialists. Yet, it would be difficult to draw a straightforward one-to-one corresponding relationship between the body parts consumed and workers' potential social status given the result of the comparative study.

6.6 Discussion and Conclusion

Before I close the discussion of this chapter, it is worthwhile to discuss two other transformative factors that have not been touched upon. First, in urban centers, the density of bones usually is low as bones are not only consumed as food but also used by other industries far from the places of consumption (Schiffer 1987). Even though no large-scale bone workshops comparable to those of the Shang (Campbell, et al. 2011; Li, et al. 2011) or Western Zhou period (Shaanxi 1980) have been found in the Han capital area, over 60,000 pieces of bone tags (*guqian* 骨签) have been discovered at the Weiyang palace 未央宫 (Zhao 1995; Zhongguo 1996) in the Chang'an capital. This discovery indicates that significant amounts of bones (probably cattle bones) in the capital area would have been reserved to make bone tools during the Han period. Second, as Wagner (2008:25, 68-69) pointed out, bones, especially ox bones, could be used in iron remelting as flux. This factor may have played a key role in transforming the taxonomic and body-part assemblages of bone remains from an iron production site. But since there are no other lines of evidence (e.g., semi-finished bone tools or production tools that can polish bones or crush bones into powder) found from the site, it is impossible to evaluate the impacts of these issues on faunal remains in the two case studies. In this regard, the discussion above is just a preliminary research on the urban and specialized food subsistence during the Han period as it cannot cover all taphonomical factors that contribute to the formation of faunal records.

Although the meat diet of working classes might be very different from other commoners because of their economic or social status, the faunal remains from Taicheng and Zhonghang suggest that the diet of iron workers was not substantially distinguished from the tradition of food consumption in common residentail sites during the Later Bronze Age. The assemblages from the Taicheng and Zhonghang sites, in fact, echo many patterns of faunal records in Central Plains China during the Western Zhou (Huang 2000) or even the Shang period. Starting from the Late Shang, cattle already played the most dominant role in sacrificial rituals (Yuan and Flad 2005) and usually accounted for the most abundant remains in faunal records from palaces, bronze foundries, bone workshops, or even just daily-live residential remains (Hu 2012; Lam, et al. 2013; Li, et al. 2010; Li, et al. 2011). More often than not, cattle and pig bone remains occur to have the highest frequencies in the assemblage. In other words, iron workers' consumption of meat did not indicate any special or exceptional characteristics that were different from the broader tradition or common subsistence practices in the precedent Bronze Age.

Besides cattle, other major taxa identified at Taicheng include dogs, pigs, sheep/goats, and horses. The taxonomic assemblage shows that workers relied heavily on domestic resources; wild resources that might have been obtained from the natural environment only sporadically appear at the site. At Taicheng, the percentage of this type of resource is even more rare than that in the faunal assemblages from other Shang-Zhou period sites in the Central Plains. Furthermore, the beef and pork was brought to the foundry in a small meat-cuts manner, and the consumption seems to concentrate on certain specific elements. In terms of the decision of killing, the kill-off patterns illustrate that livestock was specifically raised to a specific age range for killing to optimize the utilization of animals, either in terms of meat production or for other purposes like traction and pulling. All these lines of evidence stoutly support that meat resources should come from a specialized animal husbandry and well-managed meat production system.

Despite the Taicheng foundry is located in a relatively small local administrative center with no clear archaeological evidence of dense population, the patterns in faunal remains demonstrate many similarities with the food system at Zhonghang. For instance, beef was the major resource of meat and was from old-age cattle in both cases. Also, the low representation of limb bones in pig assemblages suggests, for some unknown reasons, consuming pig heads was a common practice among iron smiths in both large urban centers and medium-sized residential sites. The two cases show that not only the meat production system but also the intensity of specialization were similar between the two foundries. It is clear that Taicheng workers were intensively specialized in a craft industry in return for food, and these workers were not just part-time specialists who were organized like a household or a family-run industry.

The understanding of food production during the early imperial period, especially the textual records regarding prices of meat and labor wages, can supplement discussion of commoners' diet in their daily life. One major discovery in this study is that the assemblage of faunal remains does not match the theoretical dietary pattern of commoners or convict laborers from a textual perspective. The two iron foundries both demonstrate that cattle remains account for the major resource of meat, and poultry remains make up an extremely small portion in the assemblage. In the diet of these iron-working communities, meat did not appear to be highly restricted. In textual records, however, chicken is supposed to be the major, or even the only, source of meat for common people and laborers. Even pig should not the most important contributor to the diet of commoners or wage laborers. By synthesizing the archaeological evidence of workers' subsistence and textual evidence of commoners' diet, the result did not reiterate the prediction based on texts. Instead, workers' diet appeared to be above that of many other normal laborers or commoners.

The discrepancy between textual and archaeological evidence could be subject to various factors, as discussed before. One possible explanation is that in the community running this ironwork, at least some individuals were not convict laborers or normal hired workers. Instead, they appear to have received additional support, either in terms of money or in the form of meat, from the owners or local officials because of the importance or profitability of the industry. Alternatively, as the site pre-dates the implement of the monopoly policies (Chapter 4), the foundry might not have been completely monopolized by the local government. It is likely that the iron foundry was run by a small group of individuals, skillful craftsmen who sustained themselves through a small entrepreneur business. Most workers at the foundry might have created considerable profits through the production of iron artifacts, and eventually entitled themselves to better diets. No matter which scenario may be the case, most iron workers at Taicheng were unlikely low-status convict or corvée laborers who served the Han government.

The comparative study also provides two additional lines of information shedding light on the dietary system of iron workers at Taicheng. Since Zhonghang is situated at the center of the capital, more abundant resources would have been provided to urban dwellers or craftsmen. In contrast, Taicheng is situated in a local center that was unlikely to be as urbanized as a walled capital. Even though the Taicheng foundry was connected to specialized food production and could be considered a full-time specialized iron foundry, the type of meat consumed at Taicheng demonstrates it was a small and local iron workshop. On the one hand, the percentage of dog remains is relatively high in the assemblage from the site, and the diet overall focused more on smaller size meat cuts. On the other hand, in the Taicheng's assemblage, the percentage of deer declined in the assemblage. In other urban contexts in northern China, deer remains usually are commonly found and account for about 3~5% in the taxonomic assemblages of identified species (e.g., Ma 2010). In the case of Zhonghang, the percentage of deer is also about 4.6% of the total NISP. The drop of deer remains at Taicheng, alongside the absence of other resources like rabbit and fish, indicates the options of meat choices in this type of regional center might be more limited than that in a capital center. Although workers could obtain meat or livestock through monetary exchange, in a "simple commodity" system choices might have varied significantly in relation to the distance to the production and exchange centers.

In summary, this chapter demonstrates that faunal remains can provide an important indicator with which to evaluate the "intensity" parameter in the framework of craft specialization. Without any doubts, faunal remains at Taicheng show that meat was produced by specialists and distributed through the market system. Workers were organized in an intensively specialized manner and were not involved in meat butchery or processing. Even though the consumption seems to focus on the low-yielding parts, most workers associated with the iron foundry did not belong to low-status convict/corvée laborers or hired labor workers. Since their diet reflected in faunal remains appeared to be better than common workers, this group of workers might even belong to a small "business" that was gaining considerable profits through producing or recycling iron products for their neighbors.

CHAPTER 7

ORGANIZATION OF LABOR AND CONTROL IN PRODUCTION TECHNIQUES

Introduction

Based on the analyses of manufacturing waste and faunal remains in Chapter 5 and 6, here I attempt to synthesize the results to explore the organization of production activities and the standardization of techniques and final products. Building on the concepts and framework of organization and standardization in archaeological studies explained in Chapter 2, this chapter aims to further identify various dimensions related to standardization, or the degree of heterogeneity in the techniques employed in production (either in terms of the production of molds and other facilities) as well as the distribution pattern of remains demonstrating heterogeneity. Because of the unequal amounts of molds in all excavated features, several features that yielded remarkable numbers of molds will be selected in order to articulate the issue and reduce the biases caused by low sample numbers. The analyses below will integrate the reconstruction of techniques and the intra-site distribution pattern of debris and manufacturing waste to map out where various production sequences were situated at the site.

I address three essential and interrelated questions here:

#1 *What is the depositional process (or the site formation process) of the site? How does this factor impact the intra-site analysis of manufacturing waste and other remains?*

#2 *How were other daily activities (e.g., food consumption) organized? Was the iron production area segregated from the area reserved for residential or other daily activities?*

#3 Based upon the reconstruction of production techniques and chaîne opératoire at the site, what does the spatial organization of iron production look like? Which model of the labor organization best matches the technical profile and degree of standardization?

Through addressing the three inter-related issues, I try to test the "null-hypothesis" about a commodity foundry that I raised in Chapter 2: if the production techniques demonstrate a high level of standardization and streamlined production sequence between each feature, the concept of commodities by destination will be supported as appropriate to employ in the context of this case study. In the end, I demonstrate that, at least during the production of molds, the production techniques present variations to a certain extent between different groups of workers manufacturing the same type of molds. Workers were even allowed to present their own practices or customs by making various types of assemblage markers and spaces on molds and cores. Furthermore, molds did not pass down their final products to casting workers; molds with different markers tended to be sent to different groups of casting workers. This pattern proves that workers did not only focus on their own procedures; workers of different steps or procedures indeed communicated to each other and had some forms of collaboration. I argue, therefore, archaeological evidence from the Taicheng foundry did not match an ideal streamlined workshop that organized workers in a sequential or "assembly-line" manner.

7.1 Approach to Intra-site Spatial Study and Impacts of Taphonomy

In a commodities-targeted production site associated with a state, its organization might resemble the theoretical model of a concentrated workshop employing corvée, retainers, or non kin-based workers concentrated in one center who engage in full-time production activities. In order to test this archaeologically, this chapter identifies whether the production techniques (e.g., molds production techniques) were standardized and similar across the entire foundry. In such organizational setting, the labor should have been highly divided to streamline production. In archaeological contexts, different types of production organization should generate distinguishable deposition patterns of debris in terms of spatial clustering and compositional patterning (Carr 1984; Ferring 1984). Thus, the intra-site distribution pattern of debris should help address the issue, especially with the help of GIS (Gallotti, et al. 2011). The spatial approach used here was developed in palaeolithic archaeology (e.g., Guan, et al. 2011) to illustrate the location of activities. In the domain of historical or even proto-historical Chinese archaeology, however, the potential of this approach has not been exploited or investigated.

In previous scholarship, intra-site analysis has been explored to examine the distribution of artifacts, debris, and organization of behaviors (Carr 1984; Greenfield and Miller 2004; Hietala 1984; Simek 1989) with an aim to identify the arrangement of activities and help reconstruct social contexts of production. Without systematic garbage management and off-site discard (i.e., when the dumping of garbage or manufacturing waste targets the most convenient pits), the debris representing various procedures will reflect the concentration and segregation of various types of production or daily activities. If this assumption holds true, theoretically, debris generated by different types of products or associated with different production procedures, which were identified through scientific analysis, are likely to be segregated and separated within the excavation area.

For concentrated production sites such as Taicheng, however, this assumption seems to underestimate the complexity of human activities and their transformative impacts on archaeological records. In reality, manufacturing waste recovered from a production site is more likely to represent "secondary assemblages", which reflects a depositional process that was heavily altered by factors including maintenance of residential space and management of refuse (Killion 1990; Moholy-Nagy 1990). In Chapter 6, the taphonomic analysis of faunal remains has already demonstrated the influence of animals and weathering on faunal remains. Furthermore, since no direct evidence related to production activities (e.g., kilns or furnaces) has been identified through the archaeological work, indirect evidence, or debris of various types of manufacturing waste, provides the only record for reconstructing the organization and investigating the issue of standardization. In short, the impacts of garbage cleaning and management have to be fully taken into consideration in order to evaluate whether the distribution of debris of manufacturing waste reflects meaningful patterns on the site scale.

In a non kin-based, factory-like workshop setting, archaeolgoical evidence might present that the entire production procedures were sub-divided into different sections; the skills employed in production have to demonstrate a relatively high degree of standardization; each step of production must also be finished by independent groups of workers who only take care of one or a limited number of steps of the entire production, similar to the so-called "prescribed"[93] type of production. But having the issue of garbage cleaning and management issue in mind, this section tries to address how the post-depositional factors impact the concentration and scale of

[93] Recent ethnographical studies on casting techniques (Yang and Li 2011; Yang, et al. 2010) that are still preserved by local specialists in Yunnan provided the best counterpart evidence to discuss the organization for my case study. These examples are all agricultural tools (usually plows) casting foundries in family-run, household settings. The working area of these workshops is just adjacent to the living or residential areas. In terms of the assemblage of final products, these small foundries only focus on one major type of tool and manufacture different variations (e.g., different sizes of plows) for different purposes. In terms of the scale of workers, these cases are all very small. According to an example from Huize 会泽, the small foundry that manufactured about 1,200 piece of plows each month was run just by an owner and 6~7 workers. The owner is a specialist in using sandstone to make casting molds and cores. Except for the procedure of cupola furnace managing (filling charges, keeping the furnace, and letting iron liquid flowing out) and casting (i.e., pouring iron liquid into molds), all other procedures were taken charge of the 6~7 workers and owners but without clear divisions of the duties. Thus, the modern ethnographical work did prove that a household production setting is less likely to generate a streamlined production sequence in which each step is taken charge of by only one group of workers.

production through the study of hoe molds. Through the analysis of two indicators related to hoe molds, I try to evaluate how data, namely the assemblages of remains, were skewed by various foundry cleaning and depositional processes. Here, I want to particularly focus on hoe molds because of their smaller size and distinctive characteristics in terms of the shape and surface features. They are easy to be refitted relative to other types of molds and even ceramic vessels. The analysis of this type of remains should consequently generate an accurate result concerning refitting.

The first indicator I will focus on is the completeness of molds after all fragments were refitted. If the molds were discarded and deposited in the features directly after they were used or broken, most of the fragments, theoretically, should be found in the same feature and the refitted one should be relatively complete. In contrast, if remains were first collected and discarded at a contemporary place and then the pile of waste was dumped into several different garbage pits in several processes, the transportation would have increased the fragmentation degree of molds in these features. In other words, the more times remains were transported, the less complete they should be when they are excavated. During the fieldwork, the percentage completeness of fragments was judged and evaluated based on the comparison with a completely refitted mold. The results might not be absolutely precise, but they should be accurate enough to describe the general preservation of hoe molds in terms of their completeness.

The second indicator related to the issue is the refitting rate of mold fragments. Similar to the idea mentioned above, if the majority of remains were directly deposited into the garbage pits (i.e., fewer times of secondary deposition), the refitting rate of these remains should be higher than that produced by secondary deposition. In the study below, I will use the following formula to calculate the successful rates of molds refitting:

Refitting rate = Total fragments/fragments after refitting

According to the calculation, a higher rate represents that more molds in the assemblage can be refitted. If the rate is equal to 1, it means either all molds were entirely complete or they were too fragmentary for refitting. During the fieldwork, I was in charge of and conducted all refitting work. Also, I tried to spend relatively equal amount of time analyzing and refitting the remains in relation to the amounts that were found. Through this procedure, I try to reduce the biases in the completeness and refitting rates due to the difference in time input and the experience of analyzer.

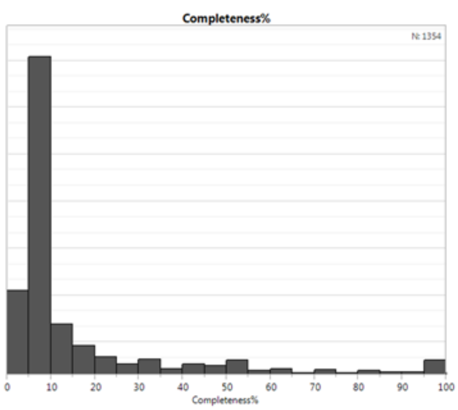


Figure 7.1 The histogram of completeness of all hoe molds identified after refitting

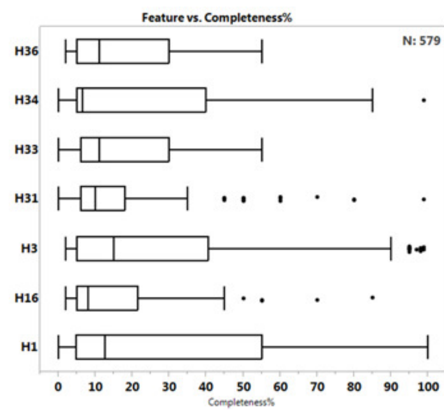


Figure 7.2 Box-plots showing the completeness of molds

In Figure 7.1, I use the histogram to demonstrate the completeness of all hoe molds after refitting. The peak concentrates on the range between 5~10%, indicating that the majority of mold remains were fragments. Even after refitting, each mold fragment only represents less than 20% of an entire piece of a hoe mold. In Figure 7.2, I also use box-pots to show the statistical result of completeness of molds from 7 features. These features were selected because of the large numbers of individual specimens found. It is interesting to note that, even though the mean of completeness is very close to each other among the selected features, the interquartile range of completeness seems to show the difference to a certain extent. The interquartile range of H1, H3, and H34 seems cover a wider area than H31, H33, and H36, indicating molds from these features are more complete. In addition, H3 have more outliers that are close to being entirely complete than other features, except H1. This figure indicates that H1, H3 and H34 yielded more complete hoe molds after refitting than other features.

Interestingly, the refitting rates of these features further testify to the suggestion mentioned above. For both side A and B of hoe molds, the refitting rates among H1, H3, and H34 are also relatively higher than those from H31, H33, and H36 (Table 7.1). In particular, the refitting rate of side B hoe molds from H31 is very low and is even close to 1, indicating the majority was made of fragments that could not be refitted together. In contrast, for H1, about half of the hoe molds could be refitted to a larger and more complete piece of molds. H34 and H3 ranked the second and third among the selected features in terms of the two indicators. Data show that about 25~40% of molds could be refitted together. This number is also significant given the large number of mold fragments that were found. Therefore, the results clearly support my proposal that the refitting rates of hoe molds can serve as an index to evaluate the garbage dumping mechanism of the site.

According to these two indicators[94], depositional processes at the site might have been quite different across these features. Mold remains from some features, such as H1, H3, and H34, were

[94] Another indicator, although it is hard to be quantitative, is the preservation of the surface. As I introduce in Chapter 5, after the carving, molds have to be pasted a layer of coating material in order to smooth the surface and facilitate the separation of the final products from molds after casting. In each feature, especially H3 and H31, hoe molds with weathered surface (e.g., H3y50), which would cause the falling off the surface layer, were identified. But this indicator was not clear enough to show difference between different features. This further supports the idea that each feature contained certain numbers of molds that were discarded in an open air for a relatively long period before entering the feature.

less likely to have been subjected to multiple-times of transportation. Nor were they assemblages generated only by the activities of garbage management. Instead, it is very likely that the majority of the manufacturing waste that was created by the same melt was eventually dumped together in the same context. In a striking contrast, remains from the other three features show very low completeness and refitting rates of hoe molds. They appear to be formed through the transformation of garbage management and selection of the place to deposit waste. Perhaps the assemblage of manufacturing waste was separately dumped into different garage pits at different times of cleaning. As a result, the assemblage of molds (and perhaps other types of remains) from these features was the result of the random discarding behavior instead of reflecting the assemblage generated by casting activities nearby.

Table 7.1 Refitting rate* of hoe molds from several major features

Side A	**H1**	**H3**	**H16**	**H31**	**H33**	**H34**	**H36**
Total fragments	20	522	43	101	25	33	18
Fragments after refitting	9	285	38	84	17	17	16
Refitting rate	*2.22*	*1.83*	*1.13*	*1.20*	*1.47*	*1.94*	*1.13*

Side B	**H1**	**H3**	**H16**	**H31**	**H33**	**H34**	**H36**
Total fragments	24	250	34	134	23	42	23
Fragments after refitting	13	147	29	126	22	19	19
Refitting rate	*1.85*	*1.70*	*1.17*	*1.06*	*1.05*	*2.21*	*1.21*

*Refitting rate = Total fragments/fragments after refitting. If no fragments could be refitted together in the assemblage, the rate would be equal to 1. But the rate would be increased when more fragments could be refitted. For instance, if the rate is equal to 2, about 50% of fragments can be refitted.

In short, through the analysis of hoe molds, the cleaning and garbage management systems are evidenced in the assemblage. Indeed, the management of garbage discard existed at the foundry in some manner. Garbage and other waste remains would not be deposited directly into dumping pits. Yet, the impacts of this factor across different features seem to be quite varied. The context of some features, such as H34, is a relatively reliable indicator to show the location where the corresponding activities reflected by remains would have taken place, whereas remains from some other features (H31) have to be treated specially and cannot be directly used to deduce the activity locations.

Since the second group of features was more relevant to the discard of manufacturing waste, and manufacturing waste from these features was less likely to be transported many times, the patterns of their spatial distribution are indicative of the location where the melting or re-melting activities took place. Furthermore, for some features such as H16, their nature might have been better and related to dumping all sorts of waste, similar to H31. Manufacturing waste from this feature might have been a mixture of remains from different procedures that took place at different times.

Based on the reconstruction of the post-depositional process, I will articulate the activities represented by the inventory of remains in two steps. In section 7.2, I first describe how the distribution patterns of remains, including ceramic, faunal remains, and manufacturing remains, reflect special activities. Even though most features have yielded a mixed assemblage including all these types of remains, a more in-depth analysis is still worth-while to address how these activities were organized within the area of an iron foundry. In section 7.3, I will take a second step to discuss the distribution pattern of remains associated with different steps or procedures in iron production. This section will discuss the calculated individual numbers for casting molds and weight for tuyères and furnace lining. In addition, I will try to study the assemblages in all Western Han features even including the features disturbed by later activities (e.g., H6 and H7), since iron production remains were only associated with the Han iron foundry and the remains might come from the nearby features destroyed by the later activities.

As I have already demonstrated in Chapter 5, the techniques employed in production involve a certain degree of variations. This chapter addresses whether variations in techniques are reflected in and correspond to the spatial distribution. By taking the factor of post-deposition or secondary deposition into consideration, the analyses in these sections try to identify if there is a clear-cut pattern in terms of different steps in production or procedures that took place at the site and to project the location where different procedures might have taken place. Section 7.4 will specifically target the issue of standardization by focusing on the spatial distribution of joining markers and spacers on molds as well as dimensional variations between different features.

7.2 Organization of Daily Life and Related Activities

Although workers at Taicheng were intensively specialized in iron prodcution, by no means were remains related to activities other than iron production absent at the site, a situation already demonstrated by the analysis in Chapter 4. The distribution of remains that were not directly associated with iron production (i.e., faunal remains and sherds) will benefit in illustrating how other daily activities were organized and incorporated into the iron production activities. To demonstrate the distribution area of these activities, I will first introduce the general distribution pattern of slag and molds—the two major types of manufacturing waste. The discussion can also provide a more comprehensive picture of the site formation and garbage cleaning procedures mentioned above. This pattern will then be compared with the intra-site distribution of the following types of remains: faunal remains, ceramic (including tiles and vessel sheds), and remains associated with other types of activities. Through juxtaposition with the investigation of post-depositional processes, I try to articulate to what extents remains of these categories represented an overlapping or segregated pattern in the spatial dimensions.

7.2.1 Distribution of molds and slag

The histogram in Figure 7.3 represents the total weight of molds (including hoes, plows, chisels, and other unidentified types) and slag from each feature. Pits H3 and H31 yielded the largest amounts of molds during excavation. Each contained more than 100 kg, and the total weight of molds from H3 is almost two times the total weight from H31. Other features also yielded certain amounts of molds, but the total weight is usually below 40 kg. For example, H7, which contained remains dating to Late Medieval period, included 30 kg of molds, suggesting that the feature might have been a feature for depositing molds of the Han period that were dug up by later human activities.

The distribution pattern of slag is slightly different from that of casting molds. Most importantly, the amount of slag excavated from H31 significantly outnumbers those found from other features, including H3. From this feature, more than 62 kg of slag or slag related remains were identified. Since this number is tremendously larger than in other features or even the combined of slag weight from all other features, this pattern indicates H31 might also have been a garbage pit specifically for dumping and cleaning up slag generated from previous production activities. During the garbage cleaning process, molds and other manufacturing waste that were dumped at contemporary places were cleaned up again, generating the low refitting rate and completeness represented by hoe molds.

In a striking contrast, H3 has only yielded less than 1 kg of slag, which is particularly low in relation to the weight of molds that were found from the same feature. The pattern reflected by the assemblage shows that the foundry workers seem to select specific features for discarding certain type of remains, which supports my suggestions mentioned above. In addition, although slag and molds were quite commonly found, there are only five features (H35, H15, H25, H5, and H4) that yielded significantly low amounts of manufacturing remains. In order to better observe the distribution patterns, I use GIS to generate a map showing the distribution of density among different features (Figure 7.4). In general, the five features are relatively clustered together and characterized by a low yield of manufacturing waste in the total assemblage. Also, since they are all located in the southern part of the excavation area, this special part of the foundry might have been related to workers' daily activities (resting or food consumption), and therefore yielded very low manufacturing waste.

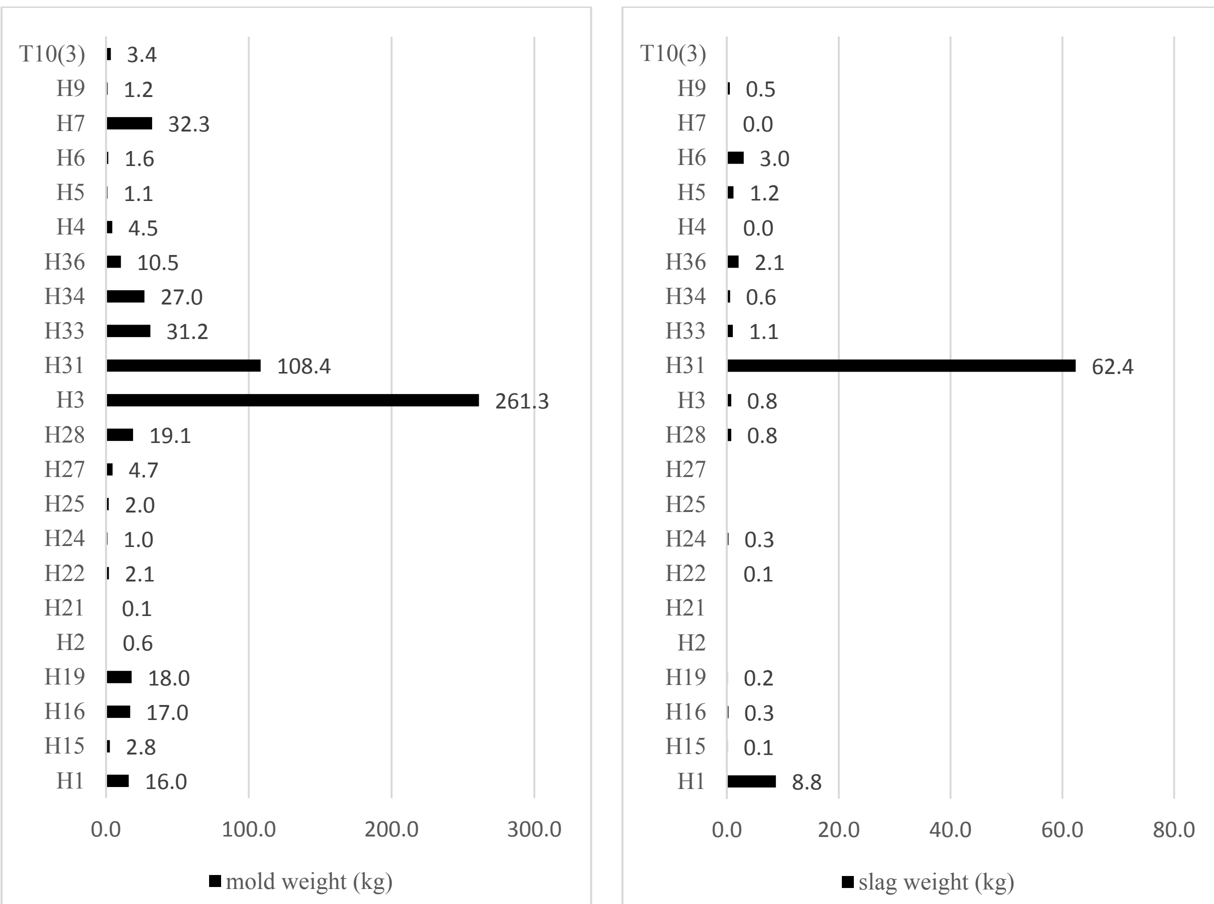
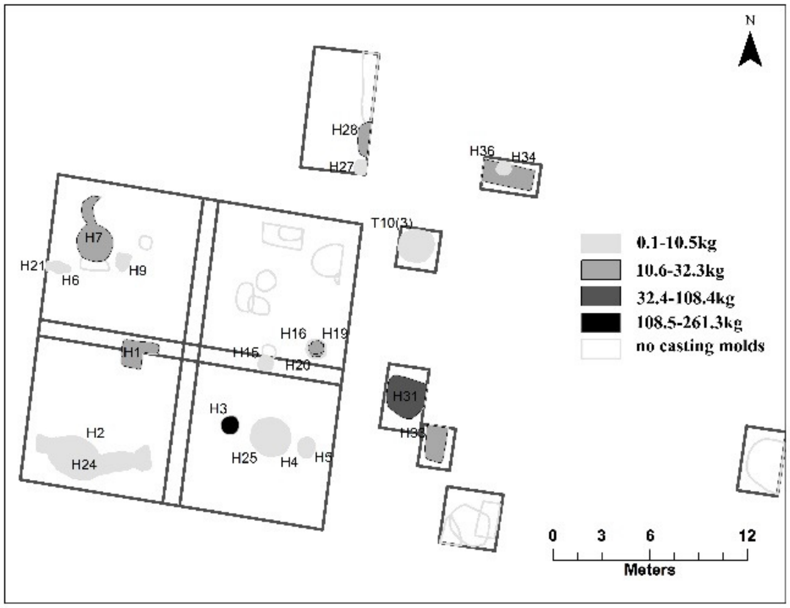
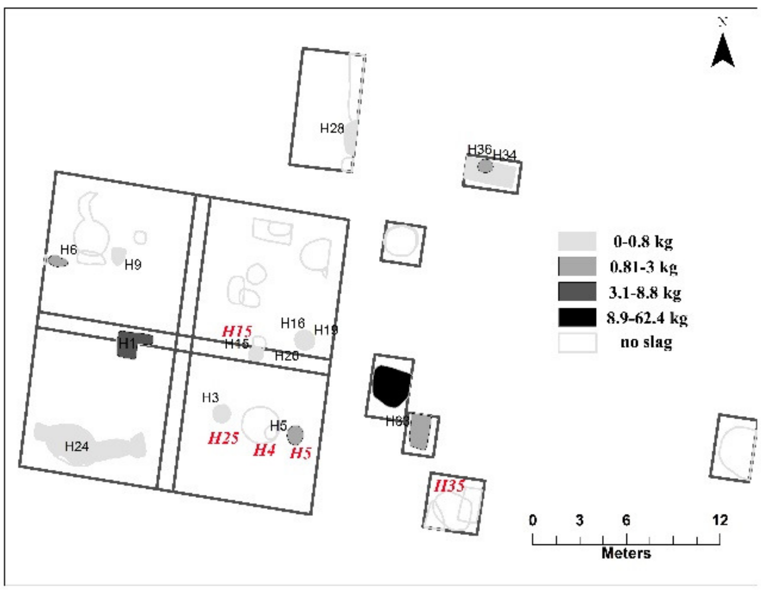


Figure 7.3 Weight of slags and molds from different features



A Casting molds



B Slag

Figure 7.4 Distribution map of casting molds and slag
(The five features that contained very few manufacturing waste but a large number of sherds and animal remains were indicated by italic labels in B)

7.2.2 Distribution of ceramic sherds

The second dimensions I will compare the intra-site distribution of ceramic sherds including tile sherds and vessel sherds. The discarding of tiles—especially a large pile of tile fragments—might indicate the location where houses would have been located. Ceramic vessels might be used for food or water storage as well as food consumption and preparation. The ceramic sherds that were found at the site belong to two categories. The first category includes *fu* or *li* tripods. These vessels are relatively small and used directly for cooking or food serving. Besides *fu*/*li*, ceramic vessels present also include *guan* jar, *pen* basin, and *zeng* steamer.

Figure 7.5 shows the total count of ceramic tile and vessel sherds. Ceramics belonging to these categories usually are large, and their functions are not limited to food cooking. In comparison with other features, H1 yielded the largest number of both tile and vessel sherds. In addition, for the five features that contained very few manufacturing remains, the counts of ceramic remains usually are relatively high. For instance, H4 yielded the second largest number of tile sherds in the assemblage. Also, in the distribution map of sherd density, the cluster of features in the southern part of the site—which yielded relatively few numbers of manufacturing waste—also seems to yield very high density of sherds.

But for the two manufacturing waste-yielding features, the ceramic assemblages present a rather intriguing pattern. H31 has yielded relatively large numbers of ceramic sherds alongside slag and casting molds. In contrast, ceramic sherds from H3 are particularly low in numbers. This may further confirm my suggestion mentioned before that H3 and H31 were garbage pits specifically for different types of remains as well as for clean-up management. H3 might seem to have been used exclusively for dumping casting molds, while H31 was used for dumping all sorts of garbage generated by the operation of the foundry and thus contained a mixed assemblage.

To better illustrate the daily life activities, I show the assemblages of major types of vessels in Figure 7.6. In the assemblage, the percentages of large storage vessels are dominant in most every feature, even though the variation between features might not indicate any meaningful pattern. It is also of interest to note that vessels specifically for serving, eating, or drinking (e.g., bowls or plates) were intriguingly infrequent in the assemblages. They were only found in H31, H16, and H4, and only represent less than 1% of the total assemblage, which is equivalent to just one or two pieces of sherds in the total assemblage.

It may be necessary to bear in mind that the southern part of the foundry—which might be more relevant to food consumption and preparation—had been partially destroyed by the moving of the Wei River; the partial excavation and discovery of the iron foundary might have skewed the reconstructed assemblages to a certain extent. But even if the assemblages of sherds only partially represent the patterns of consumption, the extremely few number of serving vessel sherds still raises an important question regarding the manner by which workers ate food or drank water. It is noteworthy that, in terms of spatial distribution, the percentages of food cooking vessels (*fu* caldron or *li* tripod) were relatively high (close to or over 10%) in H35, H4, and H25, but in the other type of garbage features the percentage of this type is generally low. This pattern might also imply that the location of these garbage dumping features are relatively far from the place where food consumption took place. Clearly, in terms of intra-site distribution, daily consumption and activities other than casting or iron making might be separated and divided into the different part of the foundry.

Indeed, in previously published ceramic or iron workshops site reports (e.g., Shaanxi et.al 2013) dating to the Qin or Warring States period, small-size serving vessels such as bowls were quite ubiquitous; the absence in the assemblage should not be completely attributed to the fact that craft workers prefer to use serving vessels that were made of alternative materials (e.g., wooden bowls). It is possible that workers just consumed and ate the food together and straight from the cooking pots or storage vessels. If it is true, I suspect that workers might not dwell at the foundry for an entire day since the assemblage of sherds did not indicate any evidence related to residential lives. If workers just came to the site to work and consumed whatever was provided to them, they might not need to prepare a lot of individual serving vessels for daily consumption.

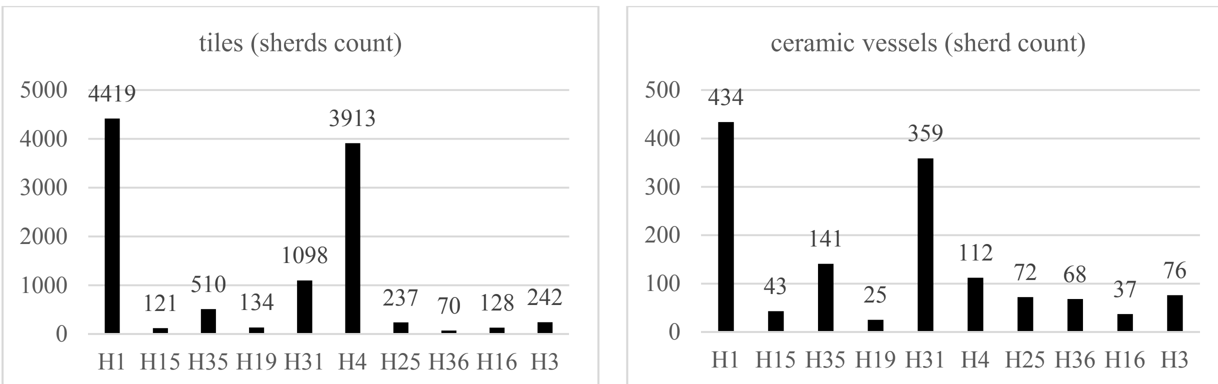


Figure 7.5 Counts of tiles and vessel sherds

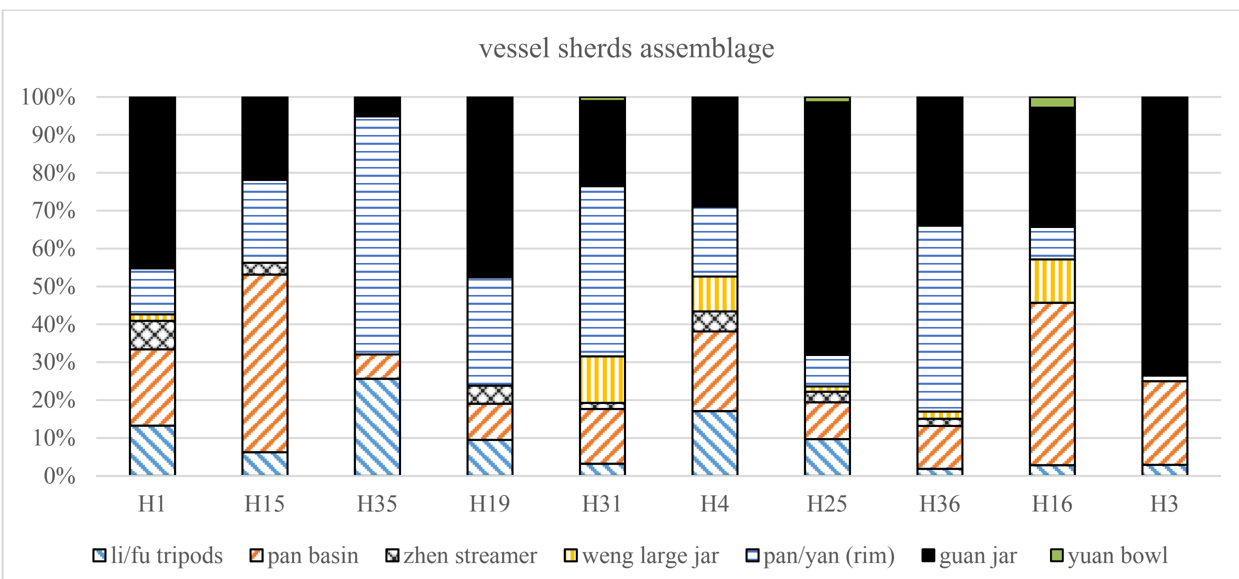


Figure 7.6 Assemblage of ceramic vessels from 10 features (the sherd number of each type is based on body and rim sherds)

7.2.3 Distribution of faunal remains

Building on the identification of species in the assemblage in Chapter 6, I present the intra-site variation regarding the total weight of bones among features with faunal remains. Figure 7.7 shows that H15, H26, and H31 contain the highest weight of faunal remains. In particular, H15 has yielded about 3.1 kg of animal bones, which is close to three times the yield of H31. In those features with large amounts of casting molds and slag, the yield of faunal remains is usually low, except H31. For instance, H3 and H34 only yielded 53 g and 29 g of animal bones respectively. For H36, faunal remains were even found primarily by flotation and sieving; large pieces of animal bones were rarely found and almost absent in the same features. On the other hand, those features that contained little manufacturing waste but were rich in ceramic sherds, such as H15, H4, and H35, generally have more animal bones. This dichotomous pattern supports my suggestion before that the southern part of the foundry was more adjacent to the place where food was consumed. The further away from this section, the fewer faunal remains were identified. Regarding H31, the rich amount of faunal remains also supports my suggestion that the feature was used for dumping all sorts of waste during clean-up, which is different from H3 in the sense that the latter was used primarily for the dumping of casting molds.

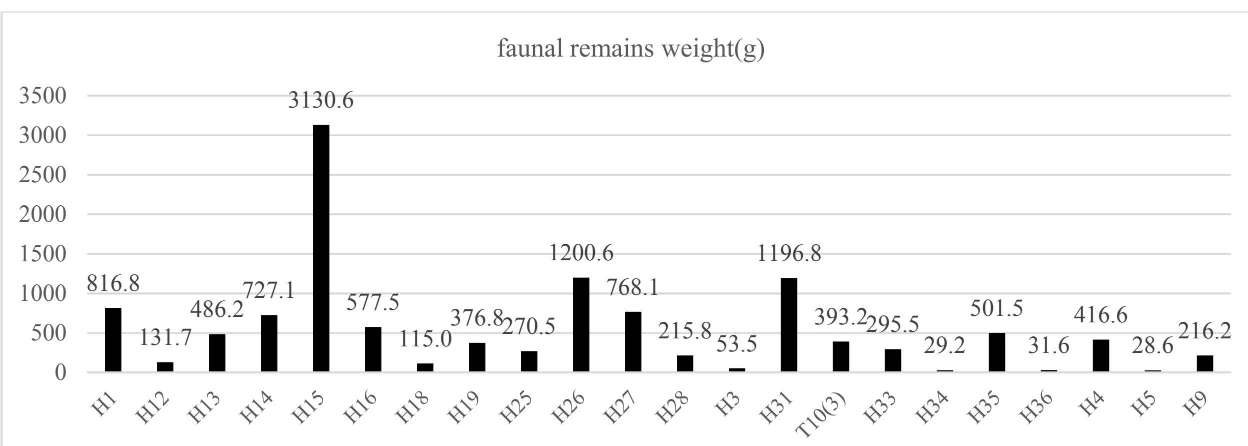


Figure 7.7 Weight of faunal remains identified from features

7.2.3 Distribution of other remains with special functions

Following the examination of manufacturing waste, sherds, and faunal remains, this section explores other types of remains that might not be generated directly by cast iron production, including reworked molds and coin models. These remains are associated with procedures that reused the waste products of cast iron production, or another co-crafting industry that utilized similar resources as the iron industry. The two types of remains indicate procedures that have not been discussed in the sections above.

a. Reworked molds

Table 7.2 Molds showing reworked signs

	cut into half	**polished**	**drilling**
H3	8	2	1
H16			
H19			
H31		2	1
H33		1	
H34	3	1	

This category involves the recycling and reusing casting molds after they were discarded (Table 7.2). The first type, or the most common type, is that the casting molds were cut into two halves by very sharp tools. This type of reworked pieces usually presents very sharp and clear-cut edges. After several casts, molds would be discarded because they were broken or the special layer on the surface lost, resulting in the molds no longer being suitable for casting. But the majority was not discarded directly. After the initial discarding, some pieces would be recycled for a number of different purposes. Molds could be used as furnace brick to construct furnace walls, or serve as lining material. This scenario has already been discussed in Chapter 5. Some discarded hoe molds were also selected to be cut in half into rectangular or square pieces. These plank pieces would then be shaped and polished into materials that were used in cast iron production, such as the cover of runner used in mold-preheating. Of course, these recycled materials would also be used for other purposes such as building blocks for repairing furnace walls. In addition, two pieces of molds in the assemblages found were drilled from both sides at the same time. It is unclear if they were reused for making some form of tools or for the practice of crafting skills employed in mold making.

In terms of the type of molds that were reworked, the majority belongs to hoe molds. Plow molds might be used for building furnace walls, but they were rarely cut into blank pieces as hoe molds. Also, molds that were cut into halves were predominately found from H3 (N=8) (Table 7.2). Three other pieces were found in H34, but none of them was found in H31 or other features. As I explained before, molds dumped into H3 and H34 might have been collected together before dumping into the garbage pit. Workers might have taken the opportunity to reuse piles of molds as desired materials for furnace repair. Eventually, the left-over raw materials or those that might not work for workers' purposes were dumped alongside other casting molds or manufacturing waste. The maximization of the value of waste products implies that workers might be subjected to the restriction of limited or tight resources and raw material supply to a certain extent. Indeed, if casting molds, raw materials, and all sorts of resources primarily relied on governmental support in a state-controlled-workshop setting, these workers might not have needed to maximize and fully reutilize raw materials. Since the evidence of mold-reuse was also mixed with other forms of remains, those who reused cast molds might have been the same group of workers who were also responsible for casting.

<u>b. Coin-making models and tools for other production</u>

Among the assemblage of all types of remains identified from the site, tools that were completely unrelated to iron production are very few in the assemblage. Even stone tools with clear and recognizable shapes were very few. In addition, only one bronze arrowhead was identified from H34 together with other manufacturing waste. This object might have been a weapon left by workers for an unknown reason on the site and is unlikely to be recycling material.

During the excavation, a total of three pieces of coin models were found from H19, H3, and H28. These pieces were called "*mufan*" (母范 master model) in general in previous site reports. This type of models was carved directly on a piece of stone with very low hardness (e.g., soapstone) to create the negative cavity of bronze coins on the model. In most cases, the making of coin molds includes several steps as follows: First, workers carve a master model, including the casting cavity of each coin, inscriptions, and runners. Using this master model, clay positive models clay were made, which could then be used to make molds with a casting cavity mirroring the same piece of master models. But since neither coin molds nor evidence related to bronze melting activities were found at the site, the Taicheng foundry might have been engaged only in the production of coin models or coin molds on a very small scale[95]. Also, since no evidence related to bronze melting or alloying was identified at the site, I suspect that mold workers at the Taicheng foundry might also have produced small numbers of minting molds, but the final products were shipped out to other minting foundries.

[95] In fact, since Taicheng predates the implement of monopoly policies on salt and iron (117 BCE), small scale of minting activities might exist at a private foundry and was not banned by the government.

To summarize the distribution patterns of several types of artifacts, it is undoubtedly the case that some forms of garbage management system existed at the site. Through this process, the assemblages of remains across different garbage features illustrate variability to a certain extent. Indeed, the intra-site comparison of remains indicates different types of transformation and transportation mechanisms imposed on these features simultaneously. By combining the indicators discussed in 7.1 and the distribution patterns of remains, the natures of features can be generalized into several categories:

1) Features specifically for manufacturing waste garbage dumping (H3, H34 and H36, and H33);

2) Features specifically for daily used vessels dumping and food waste (H35, H4, H1, H15, H25);

3) Features primarily used for dumping certain type of manufacturing waste which was collected together beforehand. Meanwhile, other types of waste could be dumped into the pit and mixed with these remains (H31, and perhaps other features yielding several types of remains at the same time).

Thus, this classification suggests that garbage management should exist at the site in some manner. For this reason, the distribution of faunal and ceramic remains at the production site is not completely homogenous. After the melting (or even perhaps during the refining activities), the waste might have been sorted for recycling or reuse (molds for building furnace walls, while slag would have been dumped into the cupola furnace again). But perhaps when the size of garbage piles was too large and prevented daily routines of production, workers would have found a garbage pit nearby to dispose part of the manufacturing waste or waste from daily production. After a certain period, these garbage piles had to be cleaned up entirely, and new garbage pits were required to dump all these remains together. Since the same types of remains in features might have come from different sources, the reliability of using the assemblages to indicate which type of activities took place varied widely. For H3, H34, H36, and other remains only yielding daily-use waste, the nature of remains is less ambiguous; they can be used more liable to deduce the adjacent daily activities reflected in the assemblage. For features like H31, we have to be more careful when using remains to understand corresponding activities.

According to this understanding, I can further outline the types of activities that appear to overlap together in brief. I suggest the southern part of the site was used as an area not directly related to iron production. Workers used this section to take breaks or recycle manufacturing waste (e.g., molds) to other usable materials (Figure 7.8). The northern part of the excavated area was used for raw material sorting, iron casting, refining, forging, repairing furnace walls and even mold making, although the specific location of these activities cannot be deduced at this stage only based on remains from garbage pits.

The study of distribution pattern and assemblages of ceramic sherds also supports that food preparation might have taken place in the southern part of the site. The study results tends to support the proposition that areas for daily activities and production activities may be teased out based on the distribution of remains. The analysis of the ceramic vessel assemblage also raises the possibility that workers might not have dwelled at the site for an entire day. If Taicheng was a highly specialized workshop, and workers would have come from different households or different villages, they were aggregated only during a certain period during a day to conduct casting or other related procedures. In this scenario, although Taicheng is a small iron foundry, its internal structure should be well organized and, in all likelihood, subdivided according to the nature of activities. By drawing all these lines of evidence together, I suggest the foundry was organized in a way that was highly specialized, non-residential, concentrated, and segregated from other economic activities. In other words, the site should be considered as a specialized iron production workshop. This workshop is also different from bronze foundry cases predating the Han period (e.g., Henan 2006; Shanxi 1993) where workers might not only dwell at the site but even were buried there since burials were commonly found.

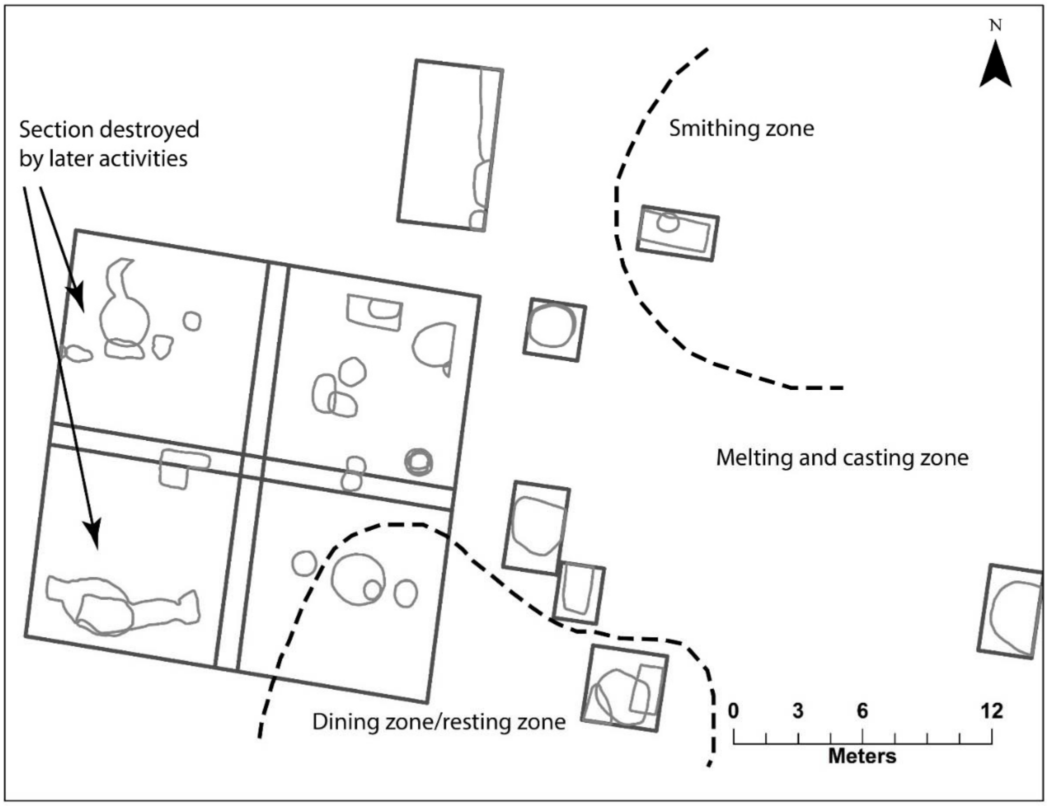


Figure 7.8 Reconstructed map showing the potential division of the excavation area of the foundry according to function

7.3 Organization of Iron Production Activity

Based on the distribution of remains associated with various types of activities, this section tries to explore the distribution of remains associated with different procedures of iron production. In order to conduct this study, I first weighed all manufacturing waste (e.g., slag and iron tools) after the initial classification from each feature. Since slag and iron pieces are fragments and irregular, the counting of weight should be more reflective of the difference in volume between each feature. For the iron remains, I calculate the total weight of each category and classify the results into 3~4 ranks and label them in the map for the convenience of demonstration.

7.3.1 Casting molds

a. Distribution of casting molds of various types

Because of the complicated depositional processes, the distribution of used casting molds was not exactly even. H3 has yielded much larger amounts of casting molds than the combined amounts of molds in all other features. For each type of casting molds, the amount of H3 is also the highest at the site. The feature with second most abundant mold remains is H31, followed by H34, H36, and H28. Some features like H1 and H27 contained very limited amounts of plow molds and cores (Figure 7.9, 7.10). But in these features, more often than not, molds or cores related to these two major categories were identified together. Furthermore, the ratio of weight between these types is not entirely similar. In the richest pits such as H3 and H31, the percentage of plow molds ranges from 40 to 60% in the total weight assemblage of casting molds, and the percentage of hoe molds ranges from 18 to 40% of the total weight (Figure 7.11). According to the co-existing patterns of casting molds in the assemblage, these types of products were very likely cast or recast together by the same melt. Consequently, they were dumped together in the same features.

In these dumping features, large and small sized of plow molds were often identified in the same context. But as I will explain in section 7.4, the ratio of different sizes molds or cores in features is different. For instance, the majority from H3 consists of large size plow molds and cores, while H31 yielded a higher percentage of small size plow molds and cores. The difference in size might be related to the type of farms or the scale of working group. One possible explanation is that casting workers at the site might include at least two groups or teams working at the same time and adjacent to each other. While each group manufactured hoes, plows, and probably chisels in each casting batch, the assemblages of the molds that each group used were slightly different. Although remains from H31 and H33 might have been subjected to more episodes of transportation, this discrepancy still supports the idea that the organization was sub-divided into different co-working groups but was not entirely based on the types of products.

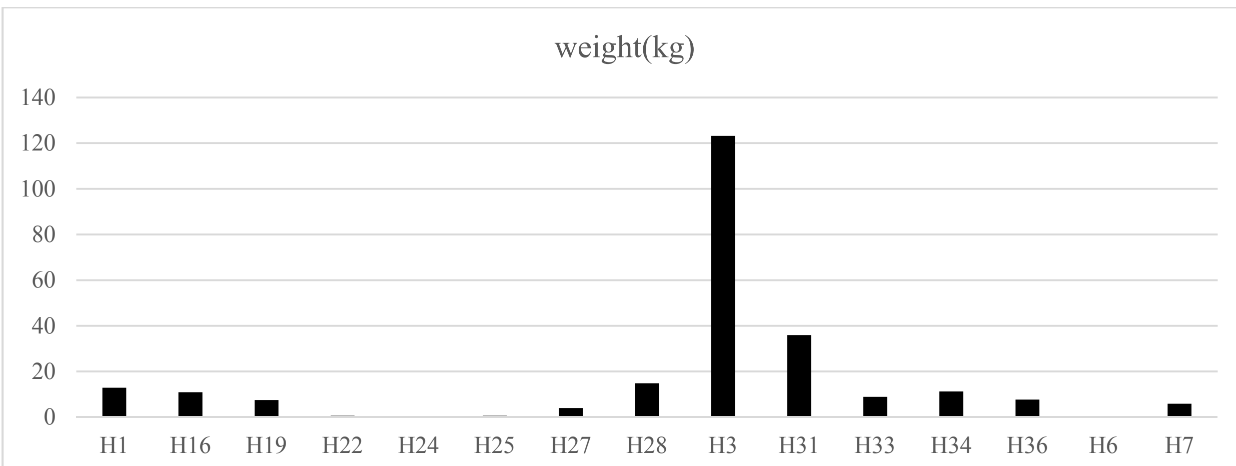


Figure 7.9 Weight of hoe molds from different features

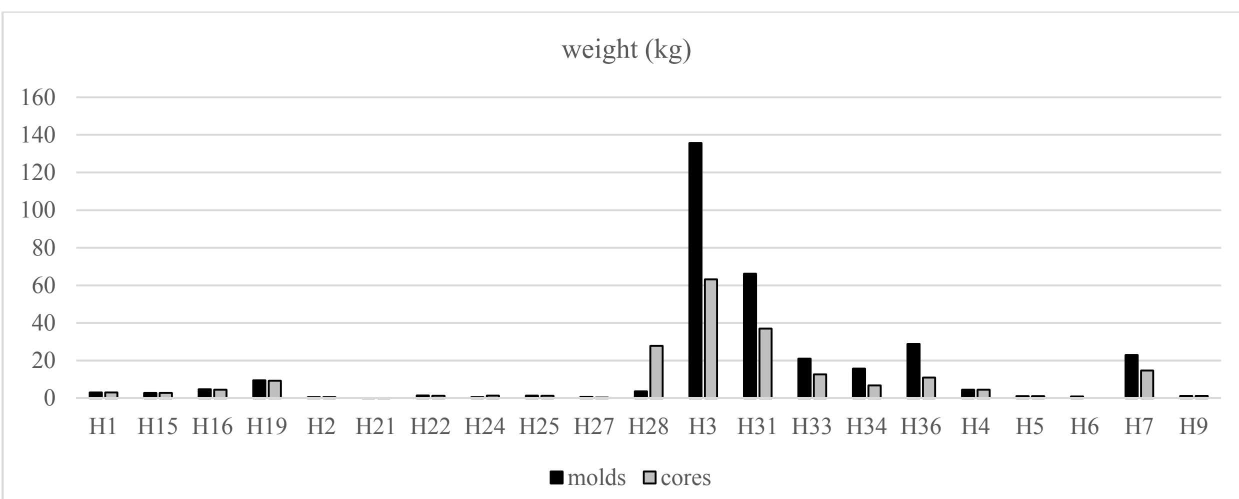


Figure 7.10 Weight of plow molds from different features

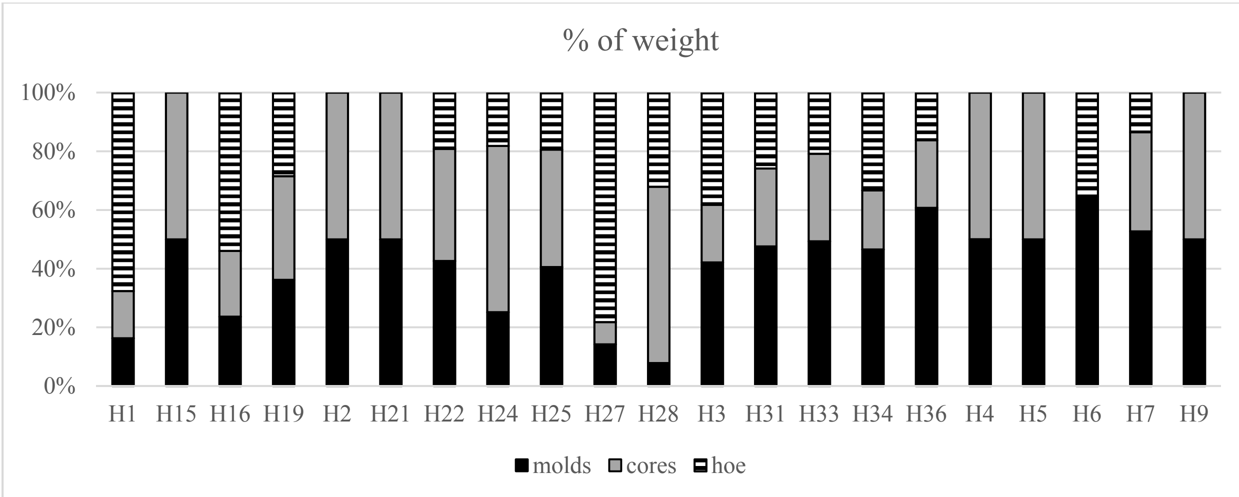


Figure 7.11 Percentage of the weight of different types of molds or cores in the assemblage

<u>b. Distribution of remains associated with mold production and unfinished molds</u>

Figure 7.12 Over-fired hoe molds (A: H31y98; B H34y14)

Table 7.3 Counting of molds that are without runners and are over-fired

	no runners	over-fired
H3	2	
H16	2	
H19	2	
H31	4	1
H33	2	
H34	1	1

In Chapter 5, I have already pointed out that at least one model from H31 might be an implement directly related to mold production. Relevant evidence related to mold-making was also found from garbage pits alongside other dumping waste (Table 7.3). For instance, H31y98 is a piece of hoe mold that was over-fired and the entire piece was distorted (Figure 7.12:A). Another piece, H34y14 (Figure 7.12:B) shows cracks on the surface because of contacting with very high temperatures. In addition, it seems that the surface layer—which may have been used for separating the object from molds after casting—was not pasted on the surface. These two pieces of molds might have been waste products from the mold-making procedure and might have been dumped directly into garbage pits. If the Taicheng foundry did not include the section of mold production, this type of waste production would have been dumped adjacent to the production site rather than transporting to the casting site. Its presence, therefore, confirms that casting molds were manufactured on the site.

It is noteworthy that these two pieces of molds do not include runners, or the casting gate at the top of the mold that was made when clay was still soft and wet before firing. In fact, hoe molds without casting gates were quite commonly found in features (Table 7.3). Some of them did not show signs of over-firing, and the surface layer is not really evident. Without making casting gates on side B, the space created by the casting gate on side A will be too narrow for pouring pig iron liquid inside into the cavity. In other words, molds without runners would not have been practical for mold casting. For some unknown reason, the mold makers put these unfinished molds into the kiln, but eventually these molds were discarded. These examples support the suggestion above that evidence about unusable waste or unfinished products from the production procedure were quite common at the site. The area for mold production might have been adjacent to the casting section, but it was either destroyed by later activities or was missed by the investigation.

7.3.2 Slag

The analysis result in Chapter 5 shows two samples from H31—a major feature yielding slag remains—generated by refined pig iron production or indirect processes. Although the classification of visual characteristics does not correspond to the nature and technique of the slag, the result is still essential in differentiating iron production techniques and identifying remains that were not generated by cast iron production. In addition, different visual characteristics might relate to different techniques or different sequences in cleaning up waste generated by the furnace. The first category of slag belongs to the waste generated by taping while the furnace was operating, while the second category of remains could not have been tapped or extracted from the furnace and had to be cleaned up after the entire melting process was complete. The nature of the third category is more complicated; this type of slag includes refined pig iron slag and furnace lining slag. Thus, if any pattern can be identified, the study of the distribution of these categories should still be useful in understanding the organization of procedures and dumping sequences of waste.

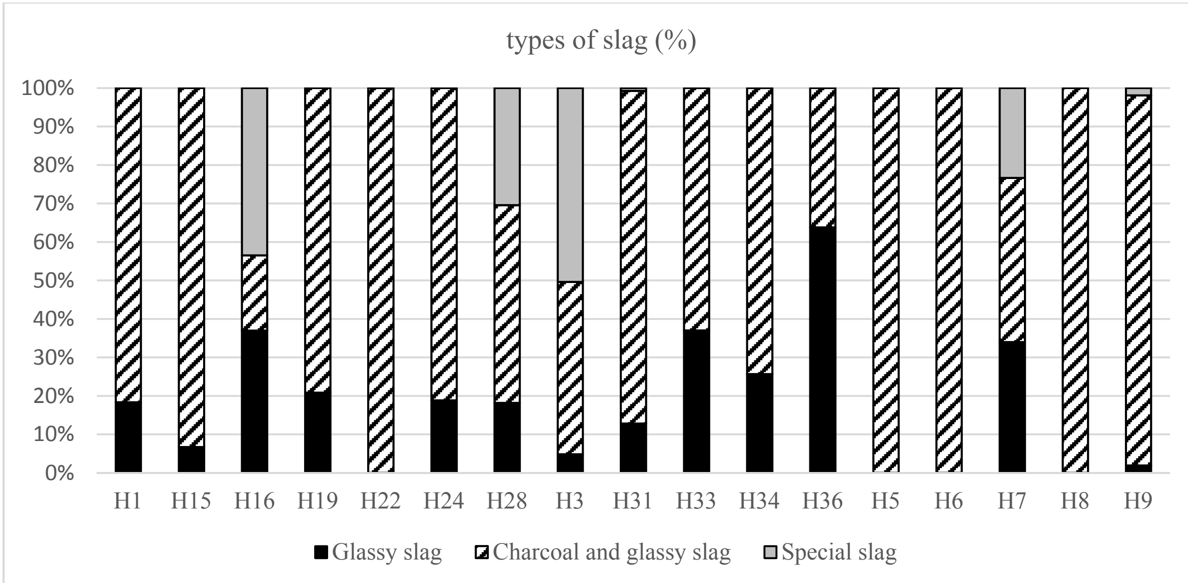


Figure 7.13 Percentage of different types of slag from features

In Figure 7.13, I present the weight assemblages of different types of slag according to visual characteristics from features with slag remains. As I discussed before, the second type of slag seems to be the most dominant type in these features. From the assemblage, we can identify that slag remains generated by different clean-up procedures were dumped into the same features with other types of remains; no feature yielded only one single type of slag. In addition, as the type of special slag was relatively uncommon in the assemblage, and the clear evidence related to refining pig iron was only identified in H31, the location where refining processes took place remains uncertain. Since it was mixed with iron melting slag, the location should not be very far away from the cupola furnace.

7.3.3. Tuyères, furnace lining, and other types of remains

Even though the types of tuyères might be related to various functions, their assemblages in the context present a mixed, mosaic pattern similar to other types of remains. In H31, the feature I hypothesize was specifically for slag and molds discard, the amount of tuyères found was limited relative to other features yielding tuyères. As some pits only were filled with casting molds (like H36 and H33) but no tuyères, there may have multiple types of discard activities, or initial separation of manufacturing waste after the production activities (Figure 7.14).

From each feature yielding tuyères, they usually yield more than one type of tuyère (e.g., H3). Since Type 3 tuyères (coarse sand tempered tuyères) were recovered from H31 and H36, perhaps the appearance of this type of tuyères was not related to any chronological changes. Remains associated with Type 1 or Type 2 tuyères are more common than Type 3. But tuyères that are related to smithing activities were only found in the eastern part of the foundry. Tuyère fragments from H16 are particularly frequent in relation to the amounts of slag, molds, and furnace linings found in this feature. In contrast, H31 yielded very few tuyère fragments in comparison with other features. Straw-tempered pipes and coarse clay pipes in some cases co-exist in the same feature (e.g., H3). But in H31 and H36 Type 1 or Type 2 tuyère fragments are very few and much less common than those of coarse quartz-tempered tuyères. As these two types of pipes might be related to two types of furnaces, I suspect that the furnaces used different types of tuyères might have located in different parts of the foundry.

For the furnace lining remains, their distribution does not follow the distribution of tuyères (Figure 7.15). The features yielding the most are H27 and H28. In terms of the furnace walls, the distribution of furnace walls/brick/burnt soil is not even across these features. H31 yielded the largest amount of furnace fragments and burnt soil (Figure 7.16); the amounts in other features by no means can compare with the yield in H31. The coarse-quartz tempered furnace walls were usually found in H31 and H36 together with burnt soil and bricks. But in H27 and H28, no piece of coarse sand-tempered furnace linings was found. Although most of these features are secondary garbage pits for dumping all sorts of waste (both manufacturing and daily-life), the discard pattern might indicate that the different categories of furnace lining represented different types of furnaces (e.g., cupola furance and refining pig iron hearths) located in different sections of the foundry. The eastern part of the entire foundry might be more adjacent to the section employing coarse quartz-tempered tuyères and furnace lining. In addition, features inside the orchard have yielded certain piece of tuyères that might have been related to forging or hammering. But these types of remains were almost absent in other features.

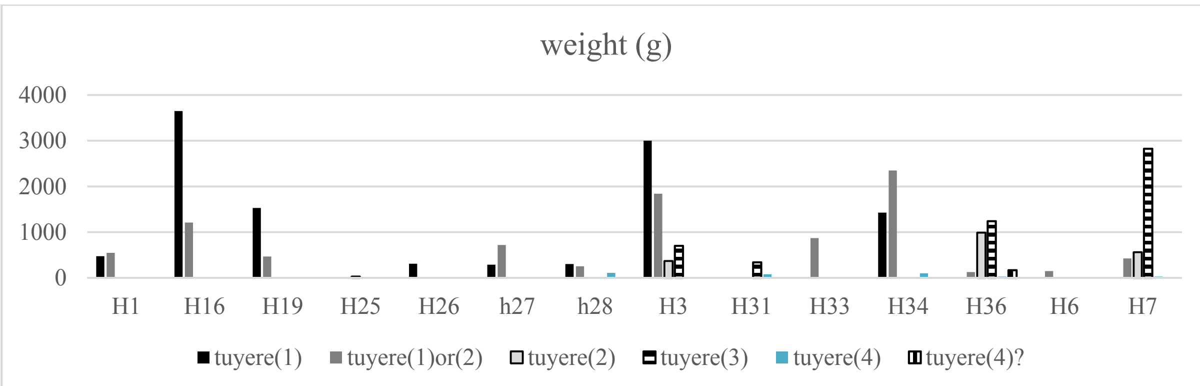


Figure 7.14 Weights of different types of tuyères from features

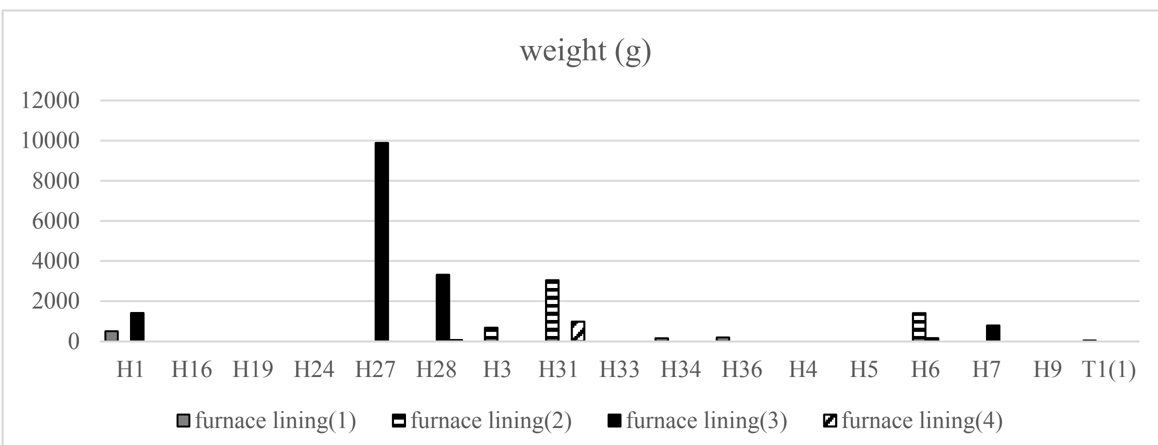


Figure 7.15 Weights of different types of furnace lining from features

In short, the yield of tuyères and furnace remains does not correspond to each other. Similar to the discard practice for molds, these remains might have been collected and piled up at contemporary storage places first before they were eventually discarded. This issue reiterates my point emphasized before that the study of intra-site distribution must fully take the issue of garbage cleaning into consideration. Meanwhile, the patterns identified also show that the separation and segregation of different types of tuyères and furnaces should not be ignored or thought to be created randomly by dumping activities. The assemblages of manufacturing waste can still be helpful for illustrating activities across at the site.

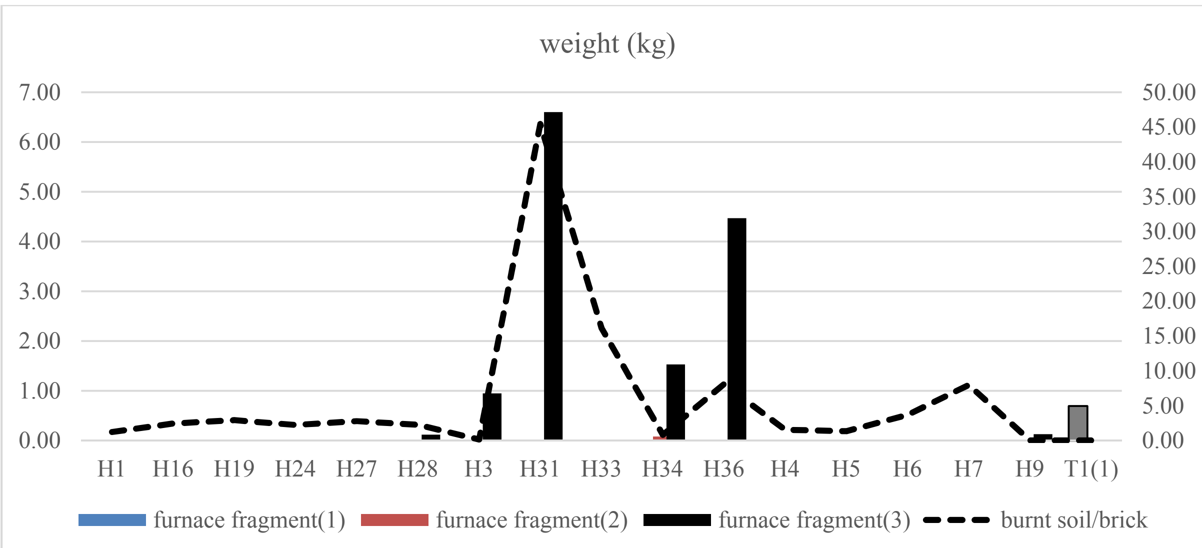


Figure 7.16 Weight of furnace fragments and burnt soil from different features
(X axis: weight of furnace fragments; Y axis: weight of burnt soil/bricks)

7.3.4 Iron pieces

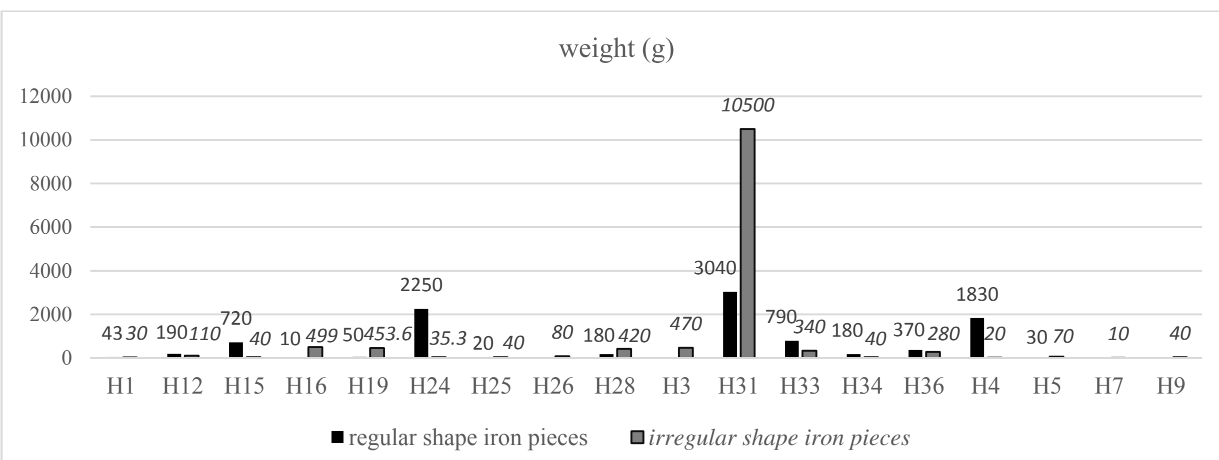


Figure 7.17 Weight of iron pieces from different features

Given the variation in the types of iron according to metallurgical analysis, these remains should represent different types of products including ingots, scrap iron collected from the neighborhood, broken tools and vessels used by iron workers, and iron remains associated with iron manufacturing. Furthermore, the distribution of iron remains as well as these subcategories also is not even across the foundry. Similar to the yield of slag, H31 is the feature that has contributed the largest amount of iron pieces (Figure 7.17). Iron pieces were found in other features (e.g., H34 and H3), and they in fact were quite widely distributed in features across the entire foundry. But the total weight of the first, second, and third categories in other features cannot compare to H31. The analysis of slag distribution has already shown that this feature yielded the largest volume of slags in comparison with other features when considering the size of features. In other words, these iron pieces were cleaned up and dumped together with slag into a single feature.

The types of iron that would be used for making tools—i.e., refined pig iron, decarburized steel, and wrought iron—were identified in H31, H34, H12, and H28. Among these samples, two pieces of bar-shaped objects, which might have served as billets for hammering and forging—were found in H28 and H31. But from other features, remains other than white or gray cast iron were rarely identified. The higher frequency of other types of techniques identified from H31 may be due to the high number of iron pieces found and consequently greater number of pieces sampled from the feature. But tool fragments or scrap iron pieces do not appear to be limited only to H31. I propose that the nature of iron pieces from other features should not be very much different from that of H31.

But if they were prepared to be recycled in production, as I proposed earlier, how can the co-existence of two types of manufacturing waste be explained? One possiblity is that originally scrap iron that was larger in size or less corroded (or better preserved) might have been mostly recycled; the materials that were discovered during excavation were, in fact, the "left-overs" because of their small size or poor quality. According to the study of modern iron industry, workers classified scrap iron into different grades before they were eventually re-molten (Carlson and Gow 1936). According to the distribution of remains, I suggest workers in the foundry might similarly have graded and classified scrap iron collected from the neighborhood and stored these categories separately before remelting or smithing. But for some unknown reasons (e.g., workers discarding less useful scrap iron in order to store new batches of scrap iron), the scrap iron that were smaller in size, more corroded, or more expensive to be recycled were dumped and discarded together with other manufacturing waste, especially in H31. Of course, in terms of iron pieces that were found in other features, their nature is more-or-less the same; they were the type of scrap iron that was difficulty to be reused and thus occasionally dumped with other manufacturing waste.

In addition to iron pieces, the excavation also identified hammer-scale through the sieving and flotation of soil sample. Veldhuijzen (2007) adopted a grid-system to divide the space surrounding a smithing hearth and screened all fill soil to collect the debris of hammer scale. Eventually, he identified hammer scales showing a concentrated distribution pattern surrounding the hearth. The distribution pattern of hammer scale, therefore, can provide an important line of evidence to extrapolate where the smithing activity might have taken place.

Even though soil samples for screening were not collected from each feature, the evidence that was generated by the soil samples this study could process already indicates certain noticeable patterns. In Figure 7.18, I listed two types of information from features that were selected: the weight of hammer scales that were collected, and the volume of soil samples that was screened and flotated. Significant amounts of hammer scales were found in H3, H33, H31, and, especially, H36. In contrast, H35 did not yield any manufacturing remains including hammer scales. Since the volume of soil samples from this feature is close to that of H36, the remarkable difference should be attributed to the abundance of hammer scales that were deposited into these features instead of sampling biases.

Hammer scales were found in significant amounts in H3, H33, H34, H31, and H36, all containing other types of manufacturing waste. In contrast, in H35, H25, and T10(1), hammer scales were extremely rare, and other manufacturing waste was too rare in these three features or stratigraphic layers. It is noteworthy that the soil volume of H36 is lower than H3, H31, H33 and H34—which is the feature that H36 was cut into, but the weight of hammer scales from H36 is much higher than the other four features. In other words, the higher weight of hammer scales found in H36 does not result from sampling bias or higher volumes of soil samples that were collected. To further confirm the origin and nature of hammer scales, soil samples from features dating to the Warring States period (H32, H38 and H39) were collected and then compared with features dating to the Western Han period. Results unquestionably prove that, in features predating the Han period, hammer scales were rarely found. It is safe to infer from these two patterns that hammer scales were not secondary depositions that were brought to the site or produced before the founding of the iron foundry.

Among all screened features, a large amount of hammer scales was found in H36. Taking the volume of soil samples into consideration (only about 38 L of soil) (Figure 7.18), the density of hammer scales is the highest among all analyzed features. Theoretically, the presence of hammer scales should correspond to distance from the smithing hearth, i.e., the closer to the smithing hearth a higher amount of hammer scales should be found, and vice versa. But there is a remarkable difference between the yield from H36 and H34. The former is a smaller pit that directly cuts in the center of the latter. Spatially, the two pits overlapped each other, but the former yielded the volume of hammer scales almost 6 times the latter. The discrepancy between these features suggests that hammer scales might have been specifically collected to be dumped into one single garbage pit, or to be reused or recycled during the remelting or refining processes. During the refining process, hammer scales could be added as flux (Buchwald and Wivel 1998) in various amounts. I suspect that hammer scales from the foundry were not only by-products of smithing but also a type of raw material that were collected and reused in the production process.

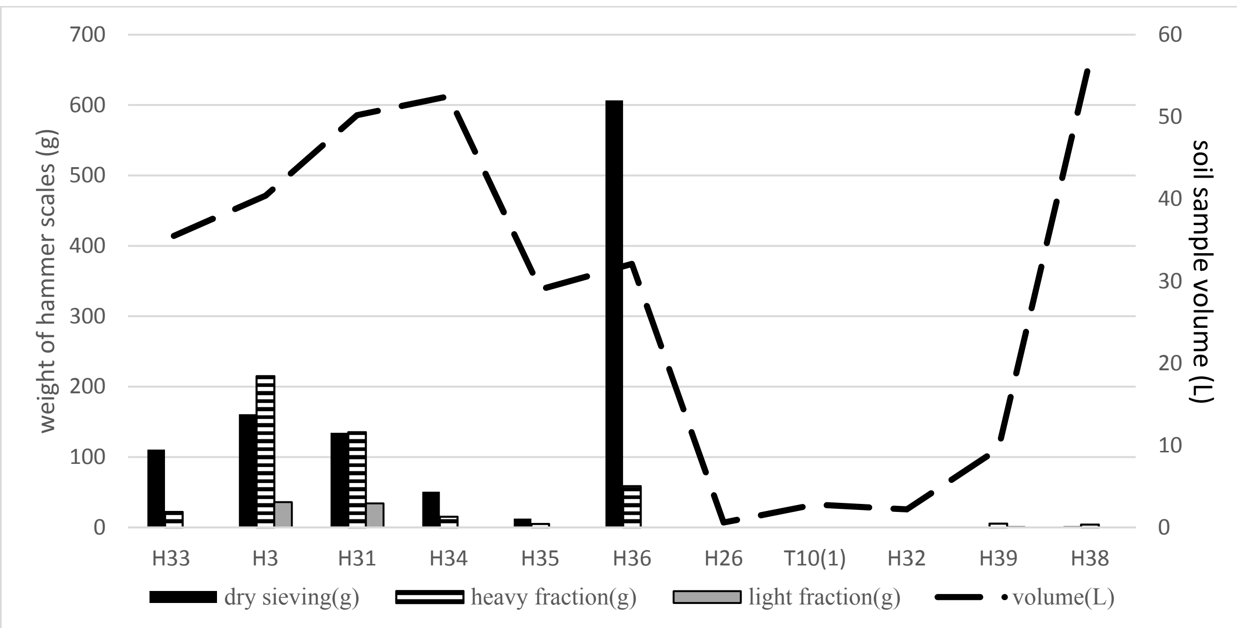


Figure 7.18 The weight of hammer scales in soil samples from 11 features that were collected and the volume of social samples that were collected
(The left side of the Y axis represents the scale of hammer-scale weight, while the right side of the Y axis represents the scale of soil sample volume)

As I discussed before, the type of tuyères used for smithing was also discovered in H34, H36, and H28. The coincidence of large amounts of hammer scales and discovery of Type 4 tuyères might suggest that, even though all hammer scales were the products of secondary deposition, H36 (and perhaps H34 and H28 as well) might have been adjacent to the area of smithing or even refining. Pig iron refining might be adjacent to the area where smithing took place. Unfortunately, the spatial distribution of different types of tuyères or furnace fragments is extremely murky. We cannot determine how far the two procedures were separated from each other, nor is it clear how many groups of workers were engaged in or took charge of the production.

Summary

Because of the complicated depositional processes and garbage management, manufacturing waste and daily activity waste in the almost every feature illustrates some sort of mixture. What made the intra-site spatial analysis of remains more difficult is that no features related to iron production (e.g., kilns and furnace) were found. Since remains were dumped into garbage pits because of secondary deposition and the garbage cleaning, the analyses above clearly demonstrate that the assemblages might not clearly pinpoint where different procedures took place.

But in the assemblages of manufacturing waste, remains associated with different steps in iron production were identified. The models for making molds and unfinished molds were found in H3 and H31. Remains that were related to unused or unfinished molds were also found (e.g., in H3 and H33). One puzzling characteristic in the assemblage is that other tools for mold making (e.g., knives or scrapers) were absent. As we discussed earlier, the production of molds involves different steps for cutting and carving in order to create the casting cavity or pouring mouth. Yet, from the excavation not even a complete knife has been found. In fact, complete iron tools, including final products or just tools used by workers, were barely found in excavated features. Most were fragments and in damaged or broken states. Therefore, I suggest that some workers of the iron foundry took charge of the mold-making procedures, and the production zone for mold making may be relatively adjacent to the working area of casting or refining activities. Furthermore, molds that were made in the foundry include not only iron casting molds but also bronze coinage molds. Although the foundry specialized in the production of iron tools, workers might employ their techniques and raw materials for making molds for other types of production. But when the foundry was abandoned or removed to other places, the toolkits might have been taken away with workers.

The analysis of waste also indicates that production procedures include not only casting but also refining and smithing. The area for these procedures inside the foundry, however, is unclear because of its small size and the transportation process of garbage remains; indicators of different types of iron production overlapped together. We can only infer from hammer scales and tuyères that smithing (perhaps including refining) were very likely to be located in the northern part of the site. After the casting activities, workers also reused and recycled molds for repairing furnace walls and other instruments that are necessary for iron production. Most importantly, this study proves that the selection of remains were well managed and even classified to dump into different features. In the pit H3, where a significant number of molds were found, only limited amounts of slag were dumped. Similarly, H33 was also a pit from which no slag has been found. On the other hand, in H31, certain numbers of molds were found along with significant numbers of slag, furnace linings and iron pieces. Perhaps given the large amount of waste generated by various procedures, it is necessary to manage the garbage or manufacturing-waste dumping system and to keep the remains to be frequently discarded.

Furthermore, coarse quartz tempered tuyères and furnace linings were particularly associated with features in the western part of the foundry. This difference in the selection and choices might be related to different functions, procedures, or personal preferences. In juxtaposition with all lines of evidence, the foundry seems to be subdivided into workers' resting or living and working areas. Within the working area, the organization was internally subdivided into different areas for different procedures because workers not only cast but also refined and forged to make or repair iron objects. This conclusion is significant in the sense that the small size of the iron foundry does not necessarily indicate that the foundry only took charge of limited steps in the entire iron production procedure.

But from a realistic viewpoint, even a family-run household foundry might separate the placement of casting, refining, and smithing. Strictly speaking, even though features show that these procedures (mold making, casting, hammering, refining, and furnace repairing) were somewhat separated but adjacent to each other, this spatial pattern still says very little about whether the workshop was a stream-lined production workship present a "prescribed" type of production. In other words, the archaeological context cannot provide the only line of evidence to evaluate whether each procedure was taken charge by the same group or different groups of workers. In the next section, I will specifically focus on signs related to both mechanical and intentional standardization in the iron production. Besides the shape and dimension of final products, this section will also focus on the skills employed in the iron melting process.

7.4 Standardization in the Skills and Production of Final Products

As I demonstrated in Chapter 5, the characteristics of casting molds production are not exactly the same but indicate certain degrees of variations. In Chapter 2, I have already explained standardization is related to two different but somehow related dimensions. The first is more relevant to the functions of products, so-called "intentional standardization". The second is related to the skills or proficiency that workers employed in various procedures of production, or "mechanical standardization". To employ this distinction in this case study, intentional standardization is relevant to the types of products (e.g., hoe vs. plow). In the section above, evidence seems to suggest that the two types of molds were generally found in almost all major mold-yielding features. But in terms of the size of plow molds and cores, large-sized plow molds and cores seem to be more dominant in the assemblage from H3, while small-sized plow molds and cores are more dominant in the remain assemblage from H31. This pattern indicates that workers either adjusted their final products according to customers' needs (i.e., casting different types of plows each time by same workers) or took charge of different types of products according to some forms of division in labor organization (i.e.g, casting different types of plows each time by different workers). In order to further articulate this issue, I focus on the markers on molds and cores as well as the measurement of their size.

7.4.1 Reassembling markers and spacers of molds and cores

On both plow and hoe molds, various type of joining signs[96] were identified. One major function is to identify the other part of the assemblage molds and facilitate the joining. But since their numbers are relatively few compared to the total numbers of molds made by these workers, another major function should be used to distinguish products by different mold workers.

There are two major types of markers found on hoe molds (Figure 7.19). The distribution of molds, nonetheless, shows an intriguing pattern. Molds with the second type of marker or signs (one-stroke markers) were predominant in H3 (17:1) (Table 7.4). But products with the first type

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[96] Undoubtedly, these signs and markers were used to facility the mold resembling and to make sure the two pieces of molds align together. But according to modern ethnographical work (Yang and Li 2011; Yang, et al. 2010), workers that are experienced in the process usually do not need to use these markers. In other words, the actual numbers of workers that made or resembled molds must be higher than the types of resembling signs.

of marker (three-stroke markers) were found alongside products with the second type of marker in H31 and H36. Although H31 and H36 represent the type of dumping garbage in which various types of waste were mixed, the predominatn pattern of the second type of marker in H3 indicates that molds made by various workers were used during different casting activities. I suspect iron workers might have been subdivided into different groups. As a result, different piles of garbage contained different assemblages of mold markers.

Another line of evidence comes from the markers on plow molds and cores. Among the five types of markers on plow cores, diamond (N=8) and triangular+rectangular-shaped markers (N=13) were predominately found in H3 (Figure 7.20; Table 7.5). Meanwhile, cores with triangular-shaped markers (N=8) were also found in the same context. But in H31, H33, H34, and H36, more often than not only the triangular-shaped marker was identified. In addition, the variation in markers is attributed to the size of cores to a certain extent. For smaller-sized cores, triangular markers were more commonly found, while the triangular+rectangular-shaped markers were only made on large size plows. These lines of evidence clearly demonstrate that molds of different types were processed and made by groups of mold markers with different customs and habits in making molds or cores. These workers particularly left traces that might not be functional in order to distinguish their products from other workers, indicating even workers manufacturing the same types of products were subdivided into multiple groups.

Figure 7.19 Two types of joining markers on the top edge of hoe molds

Figure 7.20 Two types of spacers on plow cores

Table 7.4 Counts of assembling markers on hoe molds

	|||	|	Total pieces (individual)
H3	17	1	110
H31	5	7	38

Table 7.5 Counts of assembling markers on plow cores

		▲	▲■	■	◆	Total pieces (individual)
Large	H3	10	14	2	9	43
	H31		2			20
Small	H3	3			2	9
	H31	6				18

Table 7.6 Resembling markers on plow molds

resembling markers							
upper edge							
⊥	−‾	| |	|	|_|			
1	1	10	9	2			
bottom edge							
|	−‾	| |	| | |	T	/ / /	||\\\|	7|
5	3	2	1	1	1	1	1

Table 7.7 Carving signs on plow molds

carvings signs					
			upper edge		
x	- /		→|	—‾	
3	**1**	**1**	**1**	**7**	**1**
bottom edge			back		
X					
3			**1**		

For plow molds, the markers show an even wider range of variation (Table 7.6). A total of thirteen types of markers has been identified on the upper and bottom edges. In addition, workers also carved different signs on either the top edge or bottom edge, probably to distinguish the products. Workers (either mold makers or cast workers) even carved a Chinese character 须 (*xu*) on a piece of plow mold (H3y582) (Table 7.7). Since molds and cores were made by different groups of workers, and each set of resembled casting molds could be reused several times, these markers again support my conclusion that casting workers, either beloning to different generations or different contemporary groups, might prefer to use particular sets of casting molds made by certain individuals or molds makers. In short, from a casting worker's emic prospective, even molds and cores belonging to the same types look identical, these products carried makers' identities and were not entirely the same and interchangeable.

The examination of assemblages and taphonomical factors shows that the entire site was subjected to transportation forces of various degrees. Some features might have been used particularly for casting molds, while certain features might have been used for dumping slag and all sorts of left-over manufacturing waste after cleaning-up. But for H31 and H36 (features belonging to the second type), the assemblages of the markers on casting molds do not show a highly mixed pattern in comparison with the scenario of H3. It seems that the original assemblage of mold remains from these major features have already included different inventories of molds with different markers. Transportation processes by the garbage cleaning system alone cannot explain this mixture pattern in the assemblage. This issue indicates that for each casting the batch of casting molds came from different groups of mold makers. Although each set of molds was reused for several times, molds with distinctive markers appeared to be separated and did not completely mixed even at the final discarding stage. One potential explanation is that casting workers might have alternatively used different groups of molds to cast in order to extend the life of each set of casting molds, which is in accordance with modern ethnographic records previously cited (Yang, et al. 2010). In short, even though each set of molds looks relatively identical, casting workers were highly concerned with the differentiation of molds made by different groups of workers. They even made markers on in order to signify the molds that they prefer to use for the next time and to distinguish them from other workers' molds. If so, the casting workers were similarly divided into several groups, and each group preferred to cooperate or interact with different groups of mold makers.

7.4.2 Metric measurements of casting molds

As I explain earlier, the chemical compositions of slag are relevant to a wide range of factors, which hinder the exploration of the issue of standardization that is concerned here. Instead, the measurement data of casting molds can be used as a proxy to evaluate not only the techniques employed in the production but also the manners through which final products were produced. In the analysis below, I will focus on several dimensions: the assembling signs on molds, the thickness of molds, the size of molds (e.g., the ratio between length and width), the shape and size of casting channels, and the dimensions of the casting cavity. I will calculate the Standard deviation and CV between several molds features to understand the issue of standardization in techniques, namely whether molds from these features clearly present distinctive characteristics indicating they might have been manufactured by different craftsmen.

Table 7.8 Metric measurements of hoe molds

		H1	H16	H3	H31	H34
runner length	N	5	2	61	12	4
	Mean	7.16	5.75	7.01	6.80	6.80
	Std Dev	0.53		0.74	0.24	0.65
	CV	7.43		***10.50***	3.49	9.53
runner upper width	N	4	2	64	14	3
	Mean	3.08	2.95	2.51	2.16	3.00
	Std Dev	0.65	0.49	0.37	0.36	
	CV	21.14	16.78	***14.68***	16.64	
runner lower width	N	5	2	58	11	3
	Mean	3.52	3.70	3.23	3.18	3.83
	Std Dev	0.36		0.53	0.24	
	CV	10.12		***16.31***	7.41	
length	N	5	1	***39***	1	3
	Mean	26.74	27.10	***26.76***	26.10	27.17
	Std Dev	0.21		***0.82***		0.31
	CV	0.78		***3.05***		1.12
mold top width	N	9	8	***99***	22	9
	Mean	6.76	7.56	***7.30***	7.44	7.36
	Std Dev	1.43	0.29	***0.99***	0.23	0.28
	CV	21.10	3.87	***13.63***	3.12	3.79
mold bottom width	N	6	3	***46***	6	2
	Mean	15.80	15.40	***15.70***	14.97	16.50
	Std Dev	0.44	1.44	***0.80***	0.51	0.28
	CV	2.80	9.37	***5.11***	3.40	1.71

Since the markers or signs show that molds were made by different group markers, and molds made by different makers were selected to cast objects in different times, it is valid to take one step further to evaluate whether molds from different features would be highly standardized in terms of their mechanical standardization. The purpose of the metric measurement analysis is to investigate how the molds were produced, and to what extent the final products were standardized. As I will demonstrate below, the metric measurement of hoe and plow molds/cores generate patterns that are similar to the patterns shown by joining markers. Since the available sample size from most features is too small (Table 7.8), I particularly focus on the measurement of samples from H31 and H3 to identify if the measurements would be different between these features.

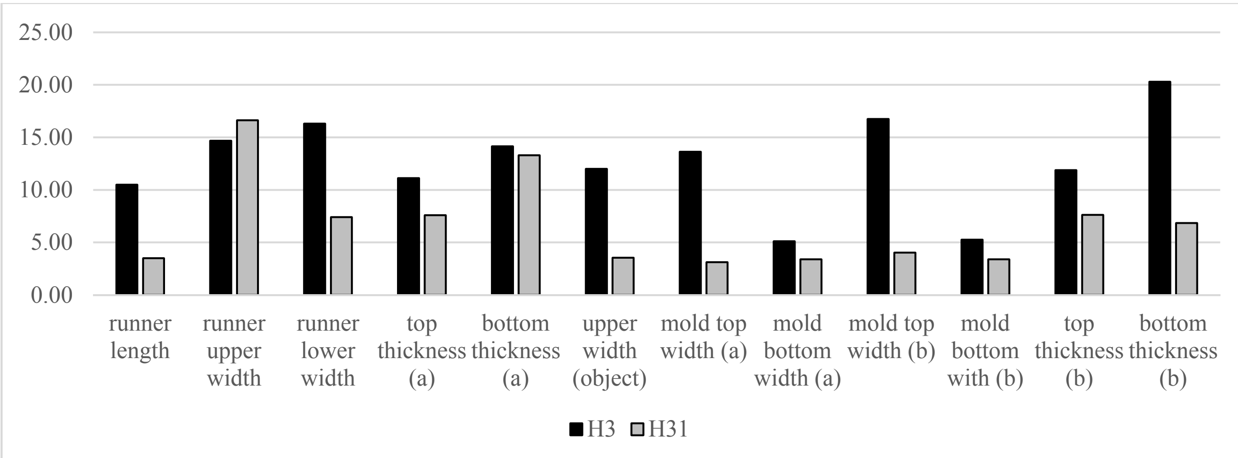

Figure 7.21 Distribution of CV values of metric measurements of hoe molds from H3 and H31

Table 7.9 Metric measurements of plow molds

		H1	H16	H19	H28	H3	H31	H34	H36
mold top width	N	4	6	3	6	26	10	6	6
	Mean	7.08	7.70	7.52	7.16	7.20	7.40	7.35	7.42
	Std Dev	0.19	0.17		0.70	1.21	0.30	0.35	0.15
	CV	2.68	2.17		9.76	16.74	4.03	4.77	1.98
mold bottom width	N	4	2	0	1	12	6	1	0
	Mean	15.78	15.60		16.40	15.18	14.97	16.30	
	Std Dev	0.56	1.98			0.80	0.51		
	CV	3.52	12.69			5.26	3.40		
top thickness	N	4	9	4	9	39	18	7	7
	Mean	3.09	3.27	3.48	3.11	3.18	3.13	3.24	3.17
	Std Dev	0.23	0.29	0.29	0.39	0.38	0.24	0.24	0.37
	CV	7.29	8.79	8.35	12.51	11.89	7.62	7.56	11.69
bottom thickness	N	5	7	5	11	41	21	2	1
	Mean	2.42	2.69	2.36	2.58	2.51	3.11	2.55	3.05
	Std Dev	0.31	0.27	0.20	0.33	0.51	0.21		
	CV	12.62	10.12	8.39	12.91	20.29	6.85		

First, I use the thickness and width of molds to compare the way that molds were made. Figure 7.21 shows the values of CVs based on the metric measurement of hoe molds froom H3 and H31. This figure shows that hoe molds from H3 demonstrate a higher CV value and a wider range of variations than H31. Using the casting runner as an example, molds from H3 are larger and longer than molds from H31, and they are also more varied. For the measurements of final products, because only very few complete molds were refitted in features except H3, products made by molds from H3 seem to be more diverse than products from H31 according to the upper width of the casting cavity. Also, the longest products made by molds from H3 might be at least 2 cm longer than the shortest ones from the same feature. If the carving of casting cavity was based on some sort of template as I suggest, this variation implies that the templates used by different groups of workers were not entirely standardized.

The difference in the size and dimensions are related to numbers of factors. The length and width of the casting cavity perhaps would impact on the function of final products. But the selection of thickness and size of molds as well as the shape of runners might be more relevant to workers' customs and practices instead of function. In addition, the thickness of molds might also be related to the care about the consumption of raw materials because thicker and wider molds would consequently consume more clay than the average. The difference demonstrated by the metric measurements show that hoe molds even used in the same episodes of casting activities were manufactured by different groups of workers.

The thickness of plow molds also shows that H3 demonstrates a wider range of variation, with a CV value higher than that of other features (Table 7.9). Perhaps the molds from H31, in general, were made by workers with greater control over the thickness. But in terms of the joining facet, molds from H3 appeared to be larger than H31. This type of difference was correspondingly identified in plow cores (Figure 7.22). Certain dimensions, such as the width on the top and the slope surface for resembling with the molds all demonstrate that H3 molds and cores tend to be relatively smaller but more varied than other features, especially the smaller size ones. This technical variation also reflects in the shape of casting runners as the measurements of H3 are smaller than other features.

These variations might be related to different reasons. First, the size of cores might be attributed to the fact that templates or master models that were used to make these cores were originally different. As a result, the final products would be different correspondingly in terms of their size and shape. In this sense, not only hoe molds but also plow molds were not entirely standardized. Second, for the features that were cut or made by hand, differences that were presented by metric measurements also indicate that each group of workers had their personalized customs and practices in other steps of mold production, which eventually led to the variations present in final products.

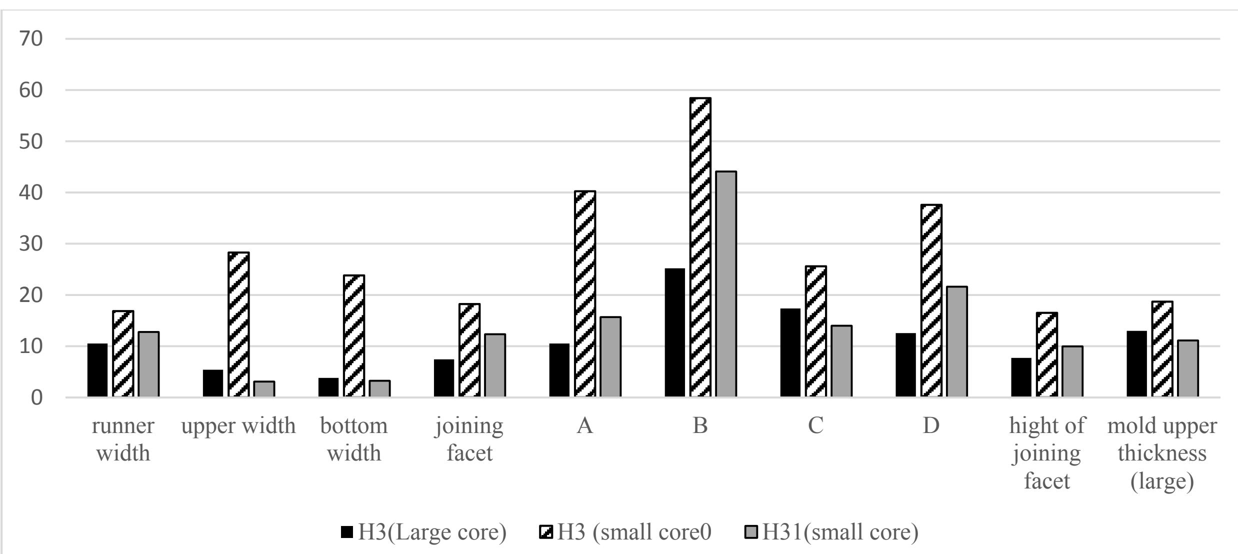

Figure 7.22 CV value of metric measurements of plow cores and molds

Since the foundry was operated at least for ninety years, molds found from the site must be produced by at least two or three generations of workers. Would the difference be attributed to the chronological change of the technique? At this stage, it is very difficult to determine since H3, H31, H33, and H34 all date to the same phase (Chapter 4), and manufacturing waste should be viewed as contemporaneous. Thus, the variations in the shapes and sizes are more likely to be relevant to differences in the control of techniques and workers' practices. Mold makers made markers on molds and used them to differentiate their work. The markers, spacers, and metric measurements all suggest that mold makers were subdivided according to the type of products. Each group of workers probably only took charge of a specific type of casting molds. According to the definition previously discussed, a "commodity workshop" has to be subdivided according to different production procedures. The evidence of distribution and the standardization of skills might support this to a certain extent. Nonetheless, the assemblage of molds in features and the intra-site variations in mold markers and shapes demonstrates that workers who took charge of the procedure of casting were fully aware of the distinctive characteristics of casting molds. Even though these casting molds were made by different hands, molds with similar markers in some cases tend to be found together in the same feature. If casting workers did randomly selected from batches of molds provided by different workers, this selection should have generated a more mosaic pattern of joining signs in the assemblage.

In addition, metric measurements show that molds from H3 might have come from multiple groups of mold maker as molds from H3 seem to be more varied than molds with the same time in H31 in terms of the sizes and characteristic features. Even the sizes of final products made by molds from H3 are more varied than those made by molds found in H31. Because of this technical variation, the same component in the mold assemblage is not really interchangeable in the assemblage. For instance, a pair of smaller-sized plow molds from H3 would need to be used with correspondingly sized cores. Cores that were dumped in H31 might not be fitted perfectly well to the assembled sets of molds in H31, even though they belonged to the smaller-size molds in general. In other words, molds in H31 present a higher degree of awareness in the control of sizes and various dimensions of molds. Different mold makers seem to stress their personal identity through markings as their signatures. To replace a component (e.g., a plow core), the casting workers were required to understand the issue of the size difference and use the products by the same group of workers. In short, casting workers were associated with specific sets of molds. Each set of molds was associated with a specific group of mold makers.

No matter whether mold making took place in the workshop or not, casting workers did not seem to randomly select groups of casting molds. These workers also might have been subdivided into several groups, and somehow connected to the division of mold markers. In this form of collaboration, casting workers understood who made their molds and constantly requested molds or cores from the same group of workers. If it is the case, mold makers and casting workers must have had connections and communications. If the actual annual requirement of casting molds was not very high, it is even possible that casting workers themselves took charge of procedures of mold making and kept their own molds and cores separately. In the study of bronze arrowheads and arrow-crossbows from the Qinshihuan mausoleum, Martinón-Torres, et al. (2014) differentiate two types of production models: single flow line production and cellular production. The first model indicates an assembly line in a constant flow, i.e., the entire procedure was broken down into different parts and each production unit only performed each procedure. In contrast, the cellular production refers to the system that each small cell or unit conducts all procedures in order to reduce the waste from mass production of single component and increase the flexibility to respond to consumers' need. By combing chemical analysis of bronze and CV analysis of metric measurements, Martinón-Torres, et al. (2014) found that bronze weapons buried with terra-cotta soldiers were manufactured by small units which conducted all procedures and produced small batches of goods each time. Thus, the organization at Taicheng might be principally similar to the "cellar production" in the sense that the entire production may be accountable for several small units at the same time. The internal division of labors was not entirely based on the type of procedure (e.g., mold making versus casting). Each group was differentiated according to its own personalized customs or practices in making products, even though the final products were still similar because of their simple forms.

7.5 Conclusion

In this chapter, I discuss potential depositional processes, the distribution patterns of various debris, and the organization reflected by these patterns. At the end of this chapter, I try to synthesize with other lines of evidence to describe a more holistic view of the specialization of the iron foundry in terms of the three major aspects of the scheme (Figure 7.23).

First, the assemblages of remains from features discovered were the results generated by complicated garbage cleaning and depositional processes. Remains of all features are a mixture of activities from several stages. Also, their natures were not exactly the same in considering the effects of artifact movement or mixing on the assemblages. For instance, H3 and H34 might contain remains moved or transported fewer times during cleaning processes than features such as H1 and H36 that include the assemblage of manufacturing waste subjected to more frequent cleaning-up and dumping. Also, the cleaning processes led to the dumping of tuyères, furnace lining, hammer-scales, and raw materials into the same contexts.

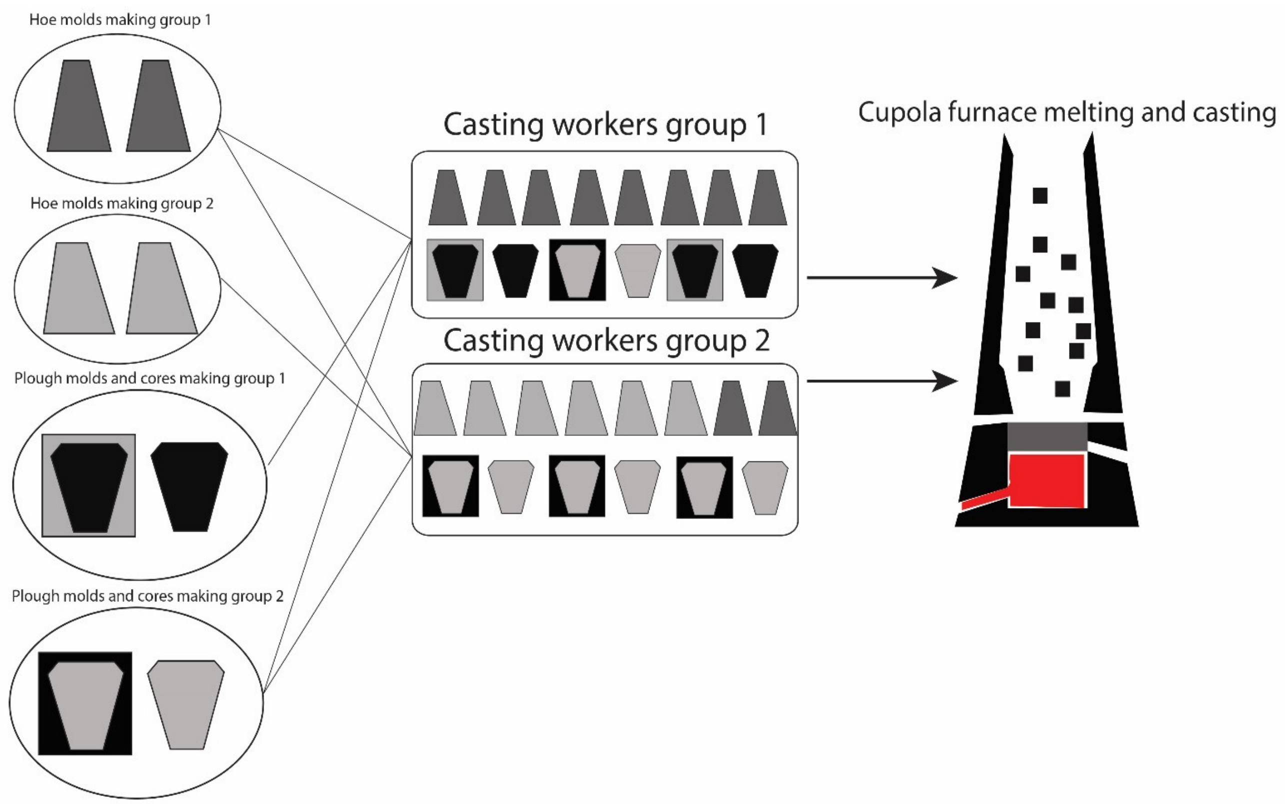

Figure 7.23 Practices in mold making and connection between workers

(This scheme shows that even the production of the same type of molds might have been conducted by different groups of workers. Meanwhile, molds were not randomly passed down to casting workers. Each group or team of casting workers seemed to have had a connection with a specific group of mold workers. The assemblages of casting molds used by different groups of casting workers might, therefore, be different)

Second, in terms of the internal organization, the excavation area seems to indicate some kind of sub-division according to the types or natures of activities. For instance, the southern area of the iron foundry might have been the resting area for workers. Iron workers might have conduct some forms of mold-reuse in the area. Other activities related to iron production were primarily in the northern part of the foundry. According to the analyses in Chapter 6, this group of iron workers was intensively specialized in the production of iron; meat resources were obtained from their neighborhood through the meat market in butchered form. In this Chapter, the study of ceramic assemblages also shows that food serving and drinking vessels are curiously missing from excavation remains. These two lines of evidence suggest that workers were not only full-time specialists; they also were not dwelling at the foundry after the casting activities. In this sense, the Taicheng foundry could be considered as a small-scale workshop—an area that was designed only for various types or procedures of iron production.

Third, regarding the organization of iron production labors, the foundry should be subdivided into several different zones taking charge of different steps of the production. Based on the analyses in Chapter 5, the basic procedures of the foundry should include at least the following steps: mold making (clay preparation, cavity making, and mold firing), raw materials preparation (e.g., fuel, flux, and scrap iron sorting, crushing, and transporting), melting and casting, refining and smithing, and garbage cleaning (e.g., repairing furnace lining, reusing casting molds, and dumping manufacturing waste). Whether Taicheng took charge of charcoal burning still cannot be addressed by the evidence we have collected so for. But Taicheng clearly was the type of foundry that was responsible for the entire production process from mold making to casting or even hammering or refining pig iron. Given the assemblage of manufacturing waste, the excavated area should be close to the casting and smithing locations. All these steps likely took place within the area of an iron foundry and were internally subdivided. Although the process of garbage cleaning led to a mixed pattern of waste assemblages in excavated features, certain indicators (slag, hammer scales, and tuyères) suggest hammering and possibly refining might be in the northeastern part of the foundry. The casting area should also be adjacent to the excavated areas. But for the procedures of mold making, since direct evidence is quite tenuous, the location for this step might have been relatively further away from the excavated area.

Fourth, the subdivision of working areas and intensive specialization do not imply that the work was sequentially streamlined and workers only took charge of individual procedures. According to the joining signs, carving, and inscriptions on plow molds, workers might make marks on molds or cores and select those that they prefer to use. Molds produced by different groups of workers were not completely interchangeable.

Fifth, analyses of various indicators related to standardization of mold production suggest that, each type of molds was finished and processed by several individuals or groups of workers. These mold makers emphasized their identities through marking signs and personal markers on molds that were more or less identical. Casting workers also marked or used signs to differentiate the goods that they preferred or selected to use for casting. In particular, although the final products were more or less similar, the sizes and shapes of casting molds reflect a consideratble degrees of skill variaiton because the same type of molds were made by different hands. Furthermore, casting workers did not seem to choose molds randomly from mold makers. As a result, molds with different types of combinations of markers or characteristics were preferably deposited in different parts of the iron foundry. I suspect that the melting and casting procedures might have been processed by groups of workers that had certain preferences in the molds they used or techniques employed in the melting. An idealized stream-lined and labor subdivided workshop model might not be fully applicable in the case study.

Taicheng foundry presents certain characteristics different from a family-run, household workshop. In addition, in comparison with the modern ethnographic case previously introduced, Taicheng was still a relatively large-scale[97] foundry (only the excavation area has already covered 600 sq. meters). The area of this modern foundry only covers 6m x 7m, and it is tremendously smaller than Taicheng. In the modern ethnographical case, workers used stone molds for casting, which can last much longer and be used many times than ceramic molds but without the need to hire a lot of mold makers. The foundry also only specialized in casting one single type of agricultural tools. In contrast, since Taichang foundry manufactured a wider range of products, its operation must have involved a large community of workers and a more complicated division of the labor organization.

In accordance with the modern case, more than 70% of recourse used by the small family workshop were old or broken plows collected from villagers. The other 30% was the scrap iron of damaged caldrons and other sorts of scrap iron. Through the recycling of scrap iron from the neighborhood, the small household foundry can self-sustain the production through the obtaining resources from nearby. The study of Taicheng remains demonstrates that raw materials include iron bars or ingots, iron weapons, fragments of caldrons or vessels, agricultural tools, and tools broadly used in daily life (e.g., knives). Nonetheless, the maintenance of its operation must have involved the transportation of raw resources from the capital center or even from production centers outside the Guanzhong Basin. Even for small foundries like Taicheng, the operation (e.g., the selection of raw materials for making molds and casting) still involved a capital-and-human resource-demanding process and required extensive forces and management; it is necessary to further contextualize the Taincheng foundry in a broader spatial context.

[97] According to Gale's descriptions (1966), at least 110 workers were required to maintain a blast furnace that could produce 85 tons of pig iron per week. Even though it is not an accurate analogy, the operation of a single cupola requires at least 10 workers to take charge of the entire cast iron production procedures.

Taicheng did not fully embody a case of a factory-like workshop by matching all characteristics that this type of workshop would expect. First of all, mold makers intentionally used markers and distinguished their identities. Even though the sizes of products were relatively standardized, the shape of assembled molds were not; thus every piece of molds of the same type is not entirely interchangeable. In order to successfully resemble a set of molds, workers needed to use molds that were made by the same workers. Also, casting workers did not randomly select molds with different markers or technical characteristics of casting; different groups of workers preferably selected and used certain groups of molds made by different makers. Even more, workers sometimes made carved signs on molds to signify the pieces of molds they would need for the next time. The reason underlying this selection and workers' preference is not totally clear. But in terms of the workshop organization, archaeological evidence contradicts the expectation that the foundry was run entirely by a streamlined model that workers just took charge of each step and used the products from previous steps regardless of who made or manufactured them. In this case, workers identities in the production processes were not completely ignored. Although archaeological evidence cannot address how their identities were presented in the final products, products of the same type from the same foundry were not exactly the same no matter from the viewpoint of producers or consumers.

One reason that products were required to be highly standardized is for market exchange (e.g., Wengrow 2008). Since products were exchanged or traded out of workers' hands and through the market system, products needed to be highly standardized in order to guarantee the quality of products from the same foundry is the same. I argue the indicators of standardization need to be discussed in the context of market exchange. The study of standardization can thus also address the "context" or "alienability" issues in the discussion of specialization that I articulated in Chapter 2. In the next Chapter, I will shift the focus to regional-scale data in order to explore how the Taicheng foundry and its final products could be integrated into the larger regional exchange network within the entire Guanzhong Basin. In addition, through the study of the market exchange system, I try to address in Chapter 9 why the foundry generated the patterns of spatial organization and standardization of the skills and techniques shown thus far.

CHAPTER 8

DISTRIBUTION OF IRON ARTIFACTS AND EXCHANGE OF COMMODITIES

Introduction

Iron objects were commonly found in the Guanzhong Basin from a wide range of archaeological contexts including palace, workshop, commoner's residential site, and, most importantly, burials. Studies on the iron objects in previous literature usually focus the typology of these artifacts (e.g., Bai 2005), but the technological aspects of these objects studied through scientific analysis has been rarely discussed, not to mention the regional variation of iron production techniques and their distribution patterns within the Guanzhong region. The production centers and provenance of large numbers of artifacts, including tools, weapons, adornment, and so on, yielded from Chang'an city still remain unknown. Even though Taicheng might potentially be one of the production centers, its small scale and size make it very unlikely to be the important source. Meanwhile, since Taicheng was unquestionably connected to a larger exchange and transportation network, clarifying and evaluating how iron production was organized and how iron products were exchanged on a regional scale is one essential step in the study.

Iron objects are usually corroded and not preserved well in most archaeological contexts. Typological study can only provide limited useful information with which to address the issue of exchange and distribution. In this chapter, I suggest two other methods that can be more beneficial in shedding light on the potential market exchange behind the artifacts. The first one is the technical comparison between artifacts from three different cemeteries, one of them being the Taicheng cemetery adjacent to the Taicheng foundry. The metallurgical analysis can show to what extent these cemeteries illustrate the technological varieties in artifacts found in different locations. In section 8.1, the background information of these cemeteries and artifacts will be first introduced. The results are be then introduced in section 8.2. One major purpose is to identify and illustrate whether differences in manufacturing techniques of objects is present between cemeteries and the Taicheng foundry.

My second approach is to adopt the “distribution approach” (Chapter 2) and compare the distributional patterns of iron assemblages from burials across the entire Guanzhong Basin. Instead of identifying the existence of a market, my purpose is to illustrate if the distance to the political core and production centers were be an important variable in the frequency of iron products that were found since the “distribution approach” assumes the market system would allow members of different ranks and status to get access to the same assemblage of goods (e.g., Hirth 1998). For this reason, tombs that might be associated with elite members (Xi'an 2004b) or officials with a rank higher than 2000 *dan* (Xi'an 2003)—which are often have entry ramps and outside storage pits—and tombs that were buried inside mausoleums are often associated with high-ranked individuals were included in the study.

The general information on cemeteries will be first introduced in section 8.1. The techniques of iron objects from selected cemeteries and the results of metallurgical analyses will be present in section 8.2. Assemblages of iron products and difference in frequencies between different cemeteries or areas will then be discussed in section 8.3. To further articulate the nature of these exchange networks, I will continue to compare the assemblages of iron objects from tombs predating the Han period—in which market economy was considered as being in its formative period—in the same area to understand whether there are other factors responsible for the patterns that we found in the Han period.

In short, this chapter tries to address two essential questions:

#1 Do regional variations in terms of manufacturing techniques exist between different cemeteries? If so, were the differences related to functional consideration or iron workers' preferences?

#2 Since the assemblages of iron products are more or less similar from cemeteries across the region, are the frequencies of burying with certain types of iron goods also similar in these cemeteries regardless of the distance to the major exchange or production centers?

By addressing the two major issues, this chapter tries to identify the model or framework of exchange that would be applicable to the case study. Furthermore, this chapter will articulate to what extent the distance to the capital or production centers, might have generated their roles in archaeological records.

8.1 Introduction to Cemeteries and Specimens of Iron Artifacts

Unlike the case studies in Mesoamerica using household and survey data, in this section I try to approach to the issue through the research on burial data. As it is explained in Chapter 4, previous archaeological works in the region focus predominantly on burial data because burials are come across frequently during construction projects. On the eastern and southern suburbs of Chang'an city, at least 20,000 Han tombs are distributed on the small plateaus surrounding Chang'an such as Longshuoyuan 龙首原, Bailuyuan 白鹿原, and Shaolingyuan 少陵原 (Hou 2004). But so far, only about 2,000 tombs have been excavated and published in full site reports (Han, et al. 1999; Shaanxi 2003a, 2008b; Xi'an & Zhengzhou 2004b) as well as numerous preliminary reports. Given that the typology of Han tombs in the Guanzhong Basin has been substantially studied before, in this study I adopt previous studies and conclusions in these reports regarding the date of collected data.

According to previous works, the percentage of Early Western Han tombs in Longshuoyuan, in general, is higher than that in other regions of the Chang'an suburbs; the cemetery area might have expanded outward alongside the development of Chang'an city and movement of migration to the capital. Outside the Chang'an city area and its outskirts, cemeteries have been an archaeological focus in works related to Han period (Figure 8.4). But these datasets might have more been subject to biases in archaeological work. Eexcavation in this vast area was not always systematic and often provided limited information about the size and scale of the entire cemeteries, not to mention that the descriptions of burial good assemblages are always very brief. So far, there are only two full site reports published about works on cemeteries outside Chang'an (Shaanxi 2004a, 2006a). Other published data were just sporadically reported during constructional projects or salvage excavations—including the Taicheng cemetery. For this reason, I need to subdivide the data in the entire Guanzhong Basin into eight areas based primarily on present-day administrative units to facilitate the study of iron object assemblages.

In studies below, all data, including metallurgical study and spatial analysis, came from published site reports, preliminary reports[98], and unpublished information provided by my colleagues from the Shaanxi Provincial Institute of Archaeology. Besides data about iron objects, I also include information about the assemblages of bronze objects. For the study of good assemblages, data of 1,564 tombs in the entire Guanzhong Basin are included (Table 1). It is noteworthy that the Taicheng cemetery—in which 295 tombs were excavated—has yielded the

[98] In the Atlas of Cultural Relics (Shaanxi volume) (Guojia 1998), burials information was published, but it only includes brief descriptions about the assemblages and their date. Since it is difficult to incorporate this information into a statistical analysis, in this research I only derive data from full site reports and preliminary reports.

largest number of tombs outside Chang'an in one single cemetery in the database. This reflects the fact that the relatively small number of tombs identified outside the capital area and their sporadic pattern must be due to biases in archaeological work and publication rather than the lack of large cemeteries outside the capital in the Han period.

According to the published data, the most commonly found iron products include four types: iron knives, iron swords, iron caldrons, and iron candle stands. Other items that were found include iron weapons (spearhead, *ji* halberd baldes, and arrowheads), iron agricultural tools (spades and axes), and iron tools for handicraft production. In the Guanzhong Basin, very limited iron samples from previous excavation were subjected to metallurgical analysis. From residential settings, only iron samples from the arsenal (*wuku* 武库) (Du and Han 2005) and Weiyang palace (Beijing 1996) were analyzed, both datasets were published as appendices in site reports. From burial contexts, the number of analyzed iron samples is even fewer (example see Liu 1999). Because of the lack of a general study of iron technology, the study of manufacturing techniques is necessary beforehand in order to delineate the characteristics of techniques and the potential provenances of objects in the capital area. In this study, samples were collected from three cemeteries in different locations, including Taicheng (Tai 邰 county in the Han period), Wanli 湾李 (Gaoling 高陵 mausoleum town), and Zhibai 纸白 (Meiyang 美阳 county) to lay down the foundation for the study of spatial allocation pattern.

This dissertation provides an invaluable opportunity for me to sample most iron tools from the Taicheng cemetery. The general information of collected samples will be introduced below. But for the other two cemeteries the condition is different. My analysis will primarily focus on Taicheng cemetery iron objects in order to use it as a foundation to understand the production system in other county-level settlements. Tombs of all these cemeteries primarily belonged to commoners in general and date primarily to the Early Western Han period. Thus, these datasets are comparable in terms of their date as well as their social background. In order to facilitate the discussion, I will introduce the background of the three cemeteries and the approach employed in the research on iron object assemblages.

Taicheng cemetery

Figure 8.1 Iron tools from the Taicheng cemetery

1.sword SDM1:11 2.knife SDM197:8 3. knife? SDM183:1 4.ring-pommel knife SDM192:4 5. knife? SDM105:1 6. ring-pommel knife SJM51:13 7. ring-pommel knife SJM51:3 8. ring-pommel knife SJM66:12 9.spade SDM21:6 10. ring-pommel knife SJM20:27 11. ring-pommel knife SJM26:8 12.spade SJM32:2 13. ring-pommel knife JM31:8 14. ring-pommel knife SDM146:5 15.ji halberd SDM213:13 16.sword SDM213:7 17. ring-pommel knife? SJM63:12

The Taicheng cemetery is in the northwest corner of the entire Taicheng site complex. A total of 295 commoners' burials have been excavated, and two-third of them date to the Early

Western Han period. From the Taicheng cemetery, 77 pieces of iron were found including 10 weapons, 19 tools, and 42 vessels like *fu* caldron and *deng* lamps. The assemblage of all iron objects from the cemetery includes three major categories: weapons, tools, and vessels. The analyses of manufacturing remains in previous chapters show that vessels clearly could not have been cast or manufactured at the Taicheng foundry. Also, since the foundry did not yield any molds for casting iron knives or iron bars, iron knives that were found from the cemetery must have been traded to the site or manufactured by the foundry using semi-finished material imported from other production centers. In addition, most of these burials were not looted before; this cemetery provides one of the best sets of information for this study. A total of 24 samples were collected, including 8 pieces of ring-head knives, 4 large knives, 4 swords, 4 small-size knives, 1 nail, 1 tube (attached to halberd), 1 axes, 1 *cha* spade, and 1 halberd (Figure 8.1).

Zhibai cemetery

This cemetery is located about 7 km northwest of present-day Famen 法门 township in Fufeng county (Shaanxi 2010), the southern edge of the Zhouyuan site. The cemetery was found and excavated in 2005 as a salvage archaeological project in cooperation with a highway construction project. A total of twenty-five tombs were found, including one Qin tomb, eighteen Western Han tombs, and six Eastern Han tombs. These individuals are supposed to have been residents of Meiyang 美阳 county in the Han period. This cemetery is much smaller than Taicheng in scale, but at least one tomb at this cemetery yielded terra-cotta figurines. Since this type of items was rarely found in commoners' tombs, the authors of the site report suggest that the cemetery may include occupants with relatively high official ranks (ibid). Nine samples, including knives and swords (Figure 8.2), were collected from three tombs, M1, M15 and M16, all of which date to the Early Western Han period.

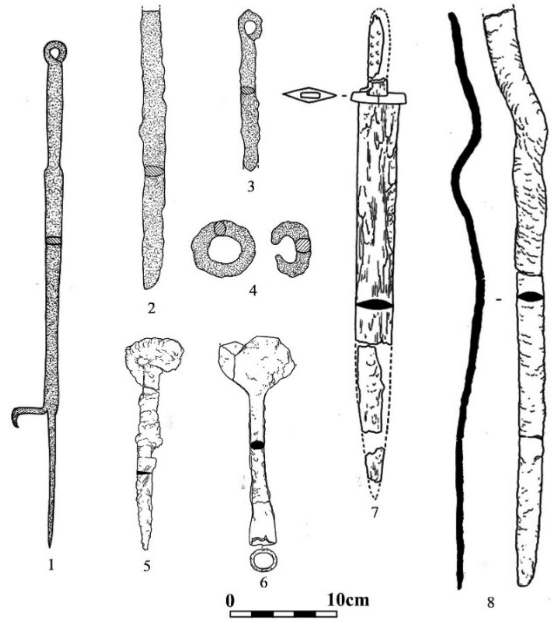

Figure 8.2 Iron tools from Zhibai cemetery

1. fork-like tool M1:10 2. knife M14:13 3. Ring-pommel knife M14:11 4. Ring-pommel knife M14:10 5. Ring-pommel knife M15:3 6. Spoon-shaped tool M16:01 7. Dagger M16:20 8. Sword? M16:22

Wanli cemetery

The Wanli cemetery is in present-day Lintong 临潼 city, which is about 30 km to the east of Xi'an. This cemetery was primarily used during the Late Warring States and Qin period, and extended towards the Early Western Han period. The number of Han tombs, however, is much lower and not comparable to tombs predating the Western Han period. Iron objects were selected from tombs relatively contemporary to Taicheng dating to the Early Western Han period. The information about this cemetery is still being analyzed by excavators, but I was allowed to sample objects from a few Western Han tombs.

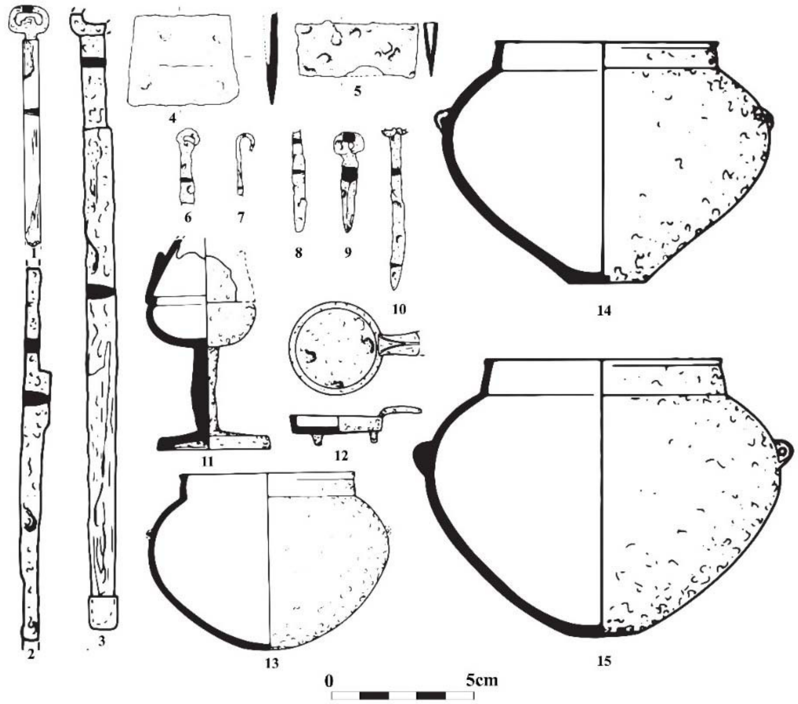

Figure 8.3 Iron objects from the Wanli cemetery

1 ring-pommel knief M110:6 2 knief M72:11 3 ring-pommel dagger M110:1 4 axe M109:14 5 spade M106:21 6 ring-pommel knief M72:14 7 hook M109:19 8 knief M109:18 9 ring-pommel knief M72:15 10 ring-pommel knief M72:9 11 incense burner M109:15 12 lamp M107:2 13 caldron M109:13 14 caldron M106:6 15 caldron M75:4

The assemblage of iron objects from the cemetery is similar to that from the Zhibai cemetery and the Taicheng cemetery including certain ring-pommel knives, swords, a spade, and certain vessels. During the Qin-Han period, the town where Wanli was located first called Ziyang 芷阳 county, and then belonged to the *Gaolingli* 高陵邑 (the mausoleum of the father of Emperor Gao). According to the size and structure of tombs, the occupants appeared to be commoners in general; no evidence shows that some of them might have been higher rank officials similar to the case at Zhibai. From this cemetery, 20 samples from 4 burials were selected for metallurgical analyses. These objects include 9 iron knives, 1 chopper, 1 spade, 1 cha spade, 1 caldron, 1 candle-stand, 1 spice-burner, 1 belt-hook, 1 chisel, and 1 hook (Figure 8.3). Unfortunately, the preservation of the selected samples are relatively poor. Among them, 9 samples were completely corroded, and no metallurgical structure can be confidently identifiable.

Besides these cemeteries, I have also collected all published data about tombs in the Guanzhong Basin from full and preliminary site reports. Figure 8.4 shows the location of these cemeteries that have been published. For the chronology of these burial data, I basically adopted the research and conclusion of the original site reports. The entire chronology of this dataset can be subdivided into three phases: Early Western Han, Middle Western Han, and Late Western Han through Wangman period[99]. Because of the solid foundation in previous literature in this regard, the dates of these burials in their conclusion are reliable. In order to facilitate the discussion, I subdivide the entire Guanzhong into 9 groups: Chang'an, Baoji, Longxiang, Xianyang, Gaoling-Lingtong, Weinan, Fufeng, Meixiang, and Yangling. For the convenience of comparison, the data are divided according to present-day administrative boundaries. Looting is a common issue in these data; more than 50% of my collected suffered from this issue and did not generate a complete assemblage of burial goods. But given the fact that looters usually looked for high valuable objects such as bronze mirrors and left iron and ceramic objects in looted tombs, I assume the factor of looting might not impose a substantial impact on the general pattern in the assemblage of iron burial goods and the conclusion based on the calculation of burial good assemblage.

The reason to combine the assemblage of iron objects with the microscopic study of iron products from an iron foundry is to address the issue of iron object distribution within the entire

[99] In this study, I incorporate tombs dated to the Xin dynasty or Wangman period into the group of the Late Western Han period, since the two periods might not be easily differentiated archaeologically.

Guanzhong area. Provenance of exchanged objects is the first question that must be addressed to illustrate the pattern of distribution (Garraty 2010). This issue, however, could not have been easily addressed in a study of iron goods that were based on cast iron and refined pig iron because most incompatible elements in iron ores already entered into slag[100] during the smelting process (see Chapter 5). In other words, it is very difficult to investigate the provenance of iron objects manufactured by the indirect method solely through their chemical compositions of SI. Some trace elements might be possible to use to differentiate the provenance of cast iron or related products, but this approach is still at its experimental and preliminary stage (Desaulty, et al. 2008; Leroy, et al. 2012) and no confirmative conclusion has been drawn yet. For this reason, I try to collect "indirect evidence" that may be helpful in addressing two issues.

Needless to say, we need to bear in mind that the nature of iron production is very different from obsidian and ceramics. This issue also hinders us from directly applying Hirth's ideal model based on the archaeological data from Mesoamerica to the Chinese context. Although Hirth (2010) and Stark and Garraty (2010) have already reflected on the issue of elite and political involvement in distribution, to what extent the political organization was involved in market exchange—which was always the case in Eary Imperial China—has not been thoroughly discussed. It is highly possible that redistribution and marketplace exchange can be characterized by juxtaposing them along a continuum, and most realistic cases are different only in terms of degrees between these two dimensions[101]. In addition, archaeological discoveries in this period which expose entire households are almost absent. That is to say, the Chinese archaeological data

[100] Meanwhile, another difficulty is due to the fact that the chemical compositions of SI of refined pig iron were derived during the fining process and represent the compositions of ash, furnace lining, and flux instead of the signals of iron ores.

[101] The coexistence of various mechanisms also might have existed in the ancient Near East, see (Lamberg-Karlovsky 2009).

still allow us to witness a sense of the issues of procurement, exchange, and redistribution on individual levels, but it is extremely difficult, if not impossible, to strictly follow the key theoretical elements and frameworks to apply the "household distribution approach" (Hirth 1998). Therefore, the analyses developed in section 8.3 and 8.4 will focus on regional variation in the assemblage of iron. These two sections try to identify through testing whether the percentage of buried iron objects in the political center would be higher than in other areas. If the percentages in the capital area is not different between the center and other areas, the allocation pattern might indicate a full-blown market system did control and manage the transportation of iron objects between the capital and other local centers.

8.2 Results of Metallurgical Study and Techniques of Iron Artifacts

This section presents the result about the regional variations of techniques employed in production through metallurgical analyses. A total of 38 objects have been sampled, but about 40% of them were not identifiable because of the poor stage of conservation. As I explained above, the sampling process requires taking the issue of conservation into consideration, and the best-preserved part of an object was always not allowed to be sampled. For this reason, the numbers of iron swords sampled were much less than iron knives. Through metallurgical analysis[102], I will first determine the types of iron and fabrication techniques employed in each cemetery. Furthermore, I will try to examine if similar types of techniques were employed in the production of the same types of products across the region

8.2.1 Taicheng cemetery

[102] In addition to metallurgical structure, SI in these samples were analyzed using SEM-EDS. Results see Appendix G. Except for special samples, I will not repeat the detail of identification standards regarding the chemical compositions of SI.

According to the analysis (Appendix H: Table H.1), 6 samples are completely unidentifiable. The 18 identifiable samples include 1 malleable iron (Appendix D: 3), 11 pieces of decarburized steel (Appendix D:4-20), 4 pieces of refined pig iron (Appendix D:1-2, 21-22, 25-26, 32-34), and 2 pieces of bimetallic objects of refined pig iron and decarburized steel (Appendix D:23-24, 27-29). In general, decarburized steel was the primary resource for iron tools and weapons. A total of 13 out of 18 samples were either made of decarburized steel or used decarburized steel as one part of welding materials. Refined pig iron and malleable cast iron were also found (N=7). Decarburized steel items would be made by decarburizing final objects or hammering white cast iron bars into a desired shape (Han and Ke 2007:609). In addition, the samples with relatively equal distribution of small pearlite and ferrite are also very likely to have been made by hammering into a desired shape (Beijing 1980:371) instead of being cast directly.

After the process of hammering or forging, surface treatment was always identified in decarburized samples. For instance, one sample (SDM197:8) shows the microstructure of ferrite and small pearlite in the center with a carbon content of about 0.1-0.2%, while the area close to the outer surface presents pearlite and grid-like ferrite structure with a higher carbon content of about 0.4% (Appendix D: 19, 20). In addition, the microstructure shows that grains were deformed, hammered and even blended. These lines of evidence show that after the raw material was hammered into shape, the surface of this object was carburized and then cold-hammered again to improve the mechanical quality. Another sample (SJM51:13) includes numbers of SI and its microstructure is basically ferrite. Furthermore, its carbon contain in the surface area is slightly higher than the core (Appendix D: 17, 18). In the ferric grains “ghost structure” because of the high content of phosphorus was identified. The entire object was made of a piece of wrought iron bloom through cold-hammering and forging.

According to the identified standard mentioned above, 6 samples in the assemblage should be identified as refined pig iron (or using refined pig iron as one component) including two knives SDM105:1 and SJM63:12 (Appendix D:1-2, 23-24), a sword SDM213:7 (Appendix D: 21-22), a spade SJM32:2 (Appendix D: 27-29), a ring-pommel knife SJM26:8 (Appendix D:25-26), and a halberd SDM213:13 (Appendix D:32-34); these samples were made by hammering an entire piece of refined pig iron bloom or welding multiple pieces of iron together. In addition, for the samples showing evidence of welding, the ways through which they were welded present a certain degree of variability. To be specific, the first three samples were just made of "welding", while the later was made of wrapping a bloom with another one.

The three samples of welding (Appendix H: Table H.1) include knife SJM26:8 (Appendix D:25, 26), which show a typical structure made by welding two pieces of bloom. In the middle of the structure, the boundary between the two pieces is a eutectic band. In the photomicrography, the upper side includes more SI with a more intensive deformation, while SI in the lower part is fewer and less deformed. The chemical compositions of Ca, Al, and Mg also show a remarkable difference between the two pieces, indicating the two iron pieces were refined by two separate processes (Appendix G). Noteworthy, in another sample SJM63:12 (Appendix D:23, 24), a long crack was identified in the center of the sample, indicating the product was made by welding two pieces of refined pig iron with lower carbon content first (these would have been recycled scrap iron) and then carburizing the surface as treatment. The second step involves welding this joint iron together with two other pieces of decarburized steel into the final object. It is very likely that, since the four pieces of scrap iron were small in size, iron smiths tried to weld them together in order to manufacture a bigger size object regardless of the difference in terms of the textural or technical difference of these materials.

The technique of these three pieces is different from the technique of the *ji* halberd SDM213:13 in the sense that it was made by "wrapping" (Appendix D: 32-34). The cross-section demonstrates that the high-carbon (ferrite+pearlite, with carbon content 0.1%) and low-carbon zones (primarily ferrite) are alternatively overlapped. In particular, the high-carbon zone appears to "wrap" the low-carbon zone. The carbon content in the surface areas, in general, is higher than the core with more pearlite and a higher carbon content (about 0.2%). In the lower carbon zone, more SI are found, and they are elongated along the extended direction. Also, in the chemical compositions Ca and Mn seem to be more fluctuated than that in the high carbon zones. In the high carbon zone, SI is relatively few without significant deformation. Thus, the two pieces of bloom were refined pig iron with different carbon content. After they had been welded together, the entire surface was processed by carbonization. Given the chemical compositions and manufacturing technique, this piece of weapon might have been either made of two pieces of bloom coming from a source completely different from the other samples or even manufactured by a completely different workshop. By synthesizing the metallurgical results together, the evidence clearly supports that iron tools and weapons from the Taicheng cemetery include local manufactured products, local recycled products, and even imported items.

8.2.2 Zhibai cemeteries

Samples from the Zhibai cemetery include two knives, one sword, one fork-like tool, and one ring-head object with unknown function. According to metallurgical analysis, two were made by refined pig iron, two pieces were made of decarburized steel, and the other two were made by wrought iron (Appendix H: Table H.2). In addition, two other samples were too corroded, and their microstructure could not be identified.

The two refined pig iron products include a knife (71359) and a fork-shaped tool (71351) (Appendix E:1~4). Object 71359 seems to be manufactured by a relatively simple technique through hammering two pieces of bloom that were welded together beforehand. The microstructure is wrought iron consisting of ferrite grains with ghost structures. The center of the sample is a band with a relatively low-carbon ferrite grains with deformed SI. In the joining zone of the two pieces of bloom, SI is particularly concentrated and highly elongated. In contrast, the structure of 71351 indicates a more complicated manufacturing technique. The microstructure of this object is cementite pearlite, but the carbon contents and the amount of cementite increase towards to the surface. Considerable amounts of SI, which was aligned with two lines and folded in a "U" shape, indicates the raw material was forged into a flat sheet and then rolled or folded. After the folding, the entire surface was carbonized as surface treatment.

Objects 71353 and 71355 were both made by decarburized steel with extremely few SI (Appendix E:5, 6). The structure of 71353 is pearlite with very small amounts of ferrite. In contrast, artifact 71355 has ferritic pearlite structure with relatively equalized grains. This piece of object might have been made by hammering decarburized iron bloom. Artifacts 71352 and 71358 (Appendix E:7, 8) are all corroded and only preserved the wrought iron structure (pearlitic ferrite). Therefore, in terms of the techniques for making iron tools, Zhibai shows similarity with Taicheng to a certain extent. Decarburized steel was the major type of raw material for forging iron knives. Refined pig iron was also used to make tools such as forks and knives. Since no large iron tools selected from the cemetery for analysis are well preserved, the results cannot show whether some iron tools were made of recycled scrap iron.

8.2.3 Wanli cemetery

In terms of tools, samples from this cemetery that are identifiable include 3 refined pig iron objects (1 spade, and 2 knives), and 1 wrought iron object (1 iron knife) (Appendix H: Table H.3). Refined pig iron seems to be a major type of material in the datasets according to the results. In addition, welding was employed in the manufacture of two refined pig iron objects (71341 and 71332) were made through piling two pieces of refined pig iron together (Appendix F:1,2,4,5). The piece of wrought iron (71336) is relatively well preserved, but no clear traces of SI were identified. This object might have been decarburized steel. Not surprisingly, the iron vessels were made of cast iron. Objects 71326 and 71333 were made of grey cast iron. These samples both show graphite flakes (Appendix F:6, 7).

The structure of 71332 shows that the manufacture of this object employed complicated manufacture. This object is a rectangular shaped axe. Close to the back-edge of the object, the structure is a multiple-layer of high-carbon and low-carbon steel. Each layer has large amounts of highly elongated SI, which is distributed in 12-13 horizontal rows. At the center, there is a long shrinkage gap formed because of unskillful operation during the welding processes. Just above the long shrinkage, there are at least 4 layers of high carbon steel (ferritic pearlite) alternating with 3 layers of low carbon wrought iron (ferrite). After these layers had been welded together, they were folded like a U shape. Below the shrinkage, there are two layers of high carbon steel and a low carbon transitional zone. This indicates that the portion was made by welding at least 3 pieces of refined pig iron together. When these two sections were forged into shape, they were welded together to produce a large piece of bloom. According to the microstructure, the carbon content seems to be higher at the tip end with more pearlite. In particular, close to the edge spheroid pearlite was identified. These two features indicate the tip end was carburized and annealed again after it was shaped. At the final stage, the surface of the object was cold-forged as deformation of grains was found. This particular piece of object was very likely made of recycled scrap iron.

For the three refined pig iron pieces, Wanli represents some aspects of the technology that has not been found at the other two cemeteries. Object 71327 was made by refined pig iron, but its structure was homogenous and consists of pearlite (Appendix F:3). Elongated SI and phosphorous blends evenly distributed throughout the profile. All these features suggest that this object was made by hammering an entire piece of refined pig iron bloom until the entire piece of bloom was homogenized and the desired shape had been achieved. Artifact 71327 is a piece of long iron pommel-ring knife, but this type of objects from Taicheng was usually made by decarburized steel instead of an entire piece of refined pig iron. In other words, even for similar type of objects, metallurgical evidence illustrated a wide range of variation in terms of major resources and manufacturing techniques.

At these three cemeteries, ring-pommel knives are the most common type of tools in the assemblage. One potential purpose of this object is to be used as a bamboo scraping tool, and was an important part of scholar writing utensils. Previous analyses of this type of objects from mausoleum, cemeteries, and workshop (e.g., Beijing 1980) illustrate that this type of knife was also usually made of decarburized steel. But for more delicate ones such as the knife with gold inlday from the Mancheng 满城 mausoleum, it was made by welding multiple pieces of steel with different carbon contents and then folding many times, or known as hundred-folding steel, to homogenize the microstructure and to improve the quality. Among all analyzed samples, there is only one case that was made by the multiple-folding technique to increase the quality of the object, but its time of folding was by no means comparable to the one from the Mancheng mausoleum. Since the high quality products through folding might correspondingly be more expensive, commoners in the Han period might prefer to choose products that were more affordable prices.

In terms of the type of iron or steel, this metallurgical study shows that decarburized steel and refined pig iron appear to be the most commonly used materials for tool-making during the Early Western Han period. For the ring-pommel knives, decarburized steel was the dominant type of material. Other types of tools (e.g., axes, spades, etc.) and weapons would have been made of decarburized steel, refined pig iron, and even malleable iron. In comparison with the quantity of decarburized steel, the numbers of refined pig iron samples are relatively small, which might be related to several different reasons. Refined pig iron may still relatively expensive because this technique had just been developed during the Early Western Han period. In addition, since refined pig iron could generate a large piece of wrought iron that is suitable for forging and thus the production of large-size weapon, this type of materials might have been controlled in order to be used exclusively in the production of nice or high-quality or skill-demanded products. Through the study of material selection in the manufacturing process, it is clear that workers took various economic and logistic factors into consideration in order to produce the goods based on the demands and requirement of the commodity market.

At least six samples from the three cemeteries were made by welding and piling, which was employed for a wide range of purposes. For instance, the *ji* halberd from Taicheng was made by a "wrapping technique"[103] that is different from techniques for making other iron knives or even

[103] In *ji* halberd sample SDM213:13, the two pieces of iron were folded for about 4 to 5 times after they were welded together, which is slightly different from the traditional "wrapping technique" that refers to the implant of a different material to the edge of an object in order to improve quality. It is important to note that similar type of halberd was also found from the arsenal in Chang'an and Beidongshan mausoleum of a Chu King in Xuzhou. But these two pieces were made by wrought iron and bloomery iron. The difference between these cases may be related to either the location of the sample or different manufacturing traditions.

iron swords. For the knife SJM63:12 (Appendix D:23), the welding technique combined iron with different carbon content. As a result, the central part of the sample is relatively soft and extendable while the surface is harder, which will be the ideal combination of properties for a long knife or a sword (Kapp, et al. 2002; Kitada 2009; Park 2004). In addition, the welding can enlarge the original size of the entire bloom to manufacture a larger piece of an object. For the spade SJM32:2 (Appendix D:27), for example, the welding might be due to the fact that the size or volume of each piece of bloom—which might be scrap iron— was not large enough. As a result, the welding could combine several pieces of bloom together to make the bloom large enough to shape the desired form. In the object made of welding, long and wide cracks at the boundary of two joint layers are quite commonly found. As Han Rubin (1987) commented, "during the welding process to combine iron pieces of different carbon content, iron smiths must be skillfully manage and control the hearth temperature, otherwise cracks would be created at welding places." Since these products were quite commonly identified from different locations, not all iron smiths in small foundries during the Western Han period were completely skillful in employing welding techniques or managing the quality in the production of daily goods.

Given the small size and scale of the Taicheng foundry, it is unlikely that the foundry would have served as a regional production center to provide surpluses for other counties. But the comparison helps clarify the relationship between the cemetery and foundry site in various aspects. In addition, the comparison of results generated by metallurgical analyses can also provide hints at addressing questions related to exchange and trade within the capital area.

First, inside the Taicheng settlement, the comparison shows that the Taicheng cemetery contained a large numbers of iron goods that could not have been directly made or manufactured by the neighborhood foundry. Beside the large amount of iron vessels or caldrons, the basic raw material for making ring-pommel knives (iron bars of decarburized steel) must have been imported from other production centers; otherwise the iron foundry could not even manufacture tools through hammering and forging. In addition, although the Taicheng foundry could manufacture refined pig iron, certain types of weapons (e.g., *ji* halberds) still must have been imported to Taicheng from outside in the form of final products or semi-finished products. In other words, within the entire Taicheng site-complex, the foundry did not play an important role in supporting goods other than agricultural tools for residents; the entire consumption and demand of iron within the area of Tai county must have relied on external production centers and a transportation system.

Second, small technical variations did exist in the assemblage from the same cemetery and adjacent cemeteries. Previous studies (Beijing & Xuzhou 1997) show that iron workers in the Han period already were familiar with selecting materials to produce tools according to their functions and shapes. But the variation was not entirely determined by physical function. Even for the same type of iron tools, the techniques would have varied. For instance, the ring-pommel knife SJM26:8 (Figure 8.1:11) from Taicheng is obviously wider than other knives in the assemblage, as it was made by welding two pieces of materials together, which was different from the technique of other narrow-blade knives produced by decarburization techniques. From the same cemetery, SJM51:13 (knife) (Figure 8.1:6) is thicker than other samples with a wide and round profile. It was made by cold forging a piece of decarburized steel, which is the only case that I identified in these samples. Since the same type of iron products from the same cemetery illustrated a wide range of variety in terms of the employment of hammering, annealing, surface carburizing, and quenching, this pattern might have indicated either the different techniques adopted or employed by iron smiths in the same Taicheng foundry or different manufacturing locations or provenances of these objects. In short, iron objects even from the same cemetery and dating to the same phase were not necessarily made by the same techniques and materials.

Third, scrap iron seemed to be the major source of raw materials for Taicheng and other small-scale settlements. From the Taicheng and Wanli cemeteries, objects that were directly made of scrap iron or steel were identified. Besides remelting, the small iron foundries in the Guanzhong Basin also forged and hammered scrap iron into new forms of objects. In addition, the technique of welding was employed, either to enhance the quality or, more likely, to make the bloom large enough to forge into the desired shape. Recycling scrap iron might serve as one important means to provide raw materials for the local production inside the entire Guanzhong Basin.

Fourth, the study of iron objects from these cemeteries show that refined pig iron had been widely employed and distributed throughout the entire basin during the Early Western Han period. Even a small regional foundry might have produced refined pig iron (Chapter 5) on its own while recycling refined scrap pig iron at the same time. Thus, during the Early Western Han period, the refined pig iron technique must have been widely spread throughout the entire Han Empire, and its development should be a major factor responsible for the rapid change in associated economic and production changes.

Fifth, the ways in which these iron pieces were reused and recycled might show a regional discrepancy between different locations, such as Taicheng and Wanli. At Taicheng, pieces of scrap iron or steel were welded or pilled together just to enlarge the size of bloom. This practice of welding and forging might not aim to increase the physical properties of the object; the welding does not entirely homogenize the pieces of refined pig iron with different carbon content. But for the case of the spade from Wanli (71332), refined cast iron pieces—probably scrap iron—were welded, folded, and forged, and then were welded again with another piece of refined pig iron that was made by the same sequence of procedures (Appendix F:4,5). Since these objects belong to similar types of tools, their functions should not be significantly distinguished from each other. I suggest that the difference in technical choices was more relevant to the practices or customs of iron smiths[104]. This pattern also indicates that workers in different production centers might have different strategies or practices in treating and recycling scrap iron.

To summarize, the comparison of technical aspect of iron pieces provides an important line of evidence to understand the variation in the assemblage of products, even though the metallurgical analysis cannot exactly pinpoint where each iron product from these cemeteries came from. Since the Taicheng site complex might only represent a common county settlement, the organization and system of production illustrated by the analysis should be rather representative to describe the scenario in other centers throughout the entire Basin. In terms of iron tools, the majority consumed by residents needed to rely heavily on an exchange and transportation network. Local production centers might have manufactured small numbers of tools through recycling scrap iron, processing semi-finished products, and forging or hammering refined pig iron that was manufactured on their own, but certain types of products, such as ring-pommel knives, small foundries like Taicheng could not be able to finish the entire production process from the beginning (mold-making and casting) to decarburization.

[104] Although there was not any discovery related to the iron foundry in Lintong that has been reported yet, based on my suggestion here, most objects were likely to be manufactured by a local foundry nearby the Wanli cemetery.

In terms of resource procurement, recycling scrap iron was a major means for foundries inside the Guanzhong Basin to address the issue of lacking iron resources. But iron smiths in these local centers might not be fully skillful in managing the smithing temperature and formed long cracks in the microstructure. Studies also demonstrate a certain degree of technical variation in both the assemblage from the same cemetery and the assemblage from different locations. Therefore, the assemblages of iron tools in each cemetery from the entire Guanzhong Basin should represent a mixture consisting of locally manufactured and imported goods depending on exchange and market. In the next section, the assemblages of iron products from different cemeteries will be investigated to illustrate the intra-site variations in the practice of burying iron objects.

8.3 Variability in the Assemblage of Iron Artifacts in the Guanzhong Basin

This section focuses on iron objects from excavated cemeteries surrounding Chang'an city and in other counties. As production and related technology is integrated with social aspects such as the nature of the producer-consumer relationship and the status of producers (Shimada 2007:2), the excavation of the Taicheng cemetery and burial data in nearby Chang'an city offer us a valuable means to compliment an ignorance of the mechanism of redistribution and transportation. If the metallurgical analysis shows us a micro-perspective to evaluate how products were produced between different small foundries, the "distribution approach" of iron artifacts can provide another line of evidence to address, on the macro-level, how the small foundry and large market network co-operated (Chapter 2).

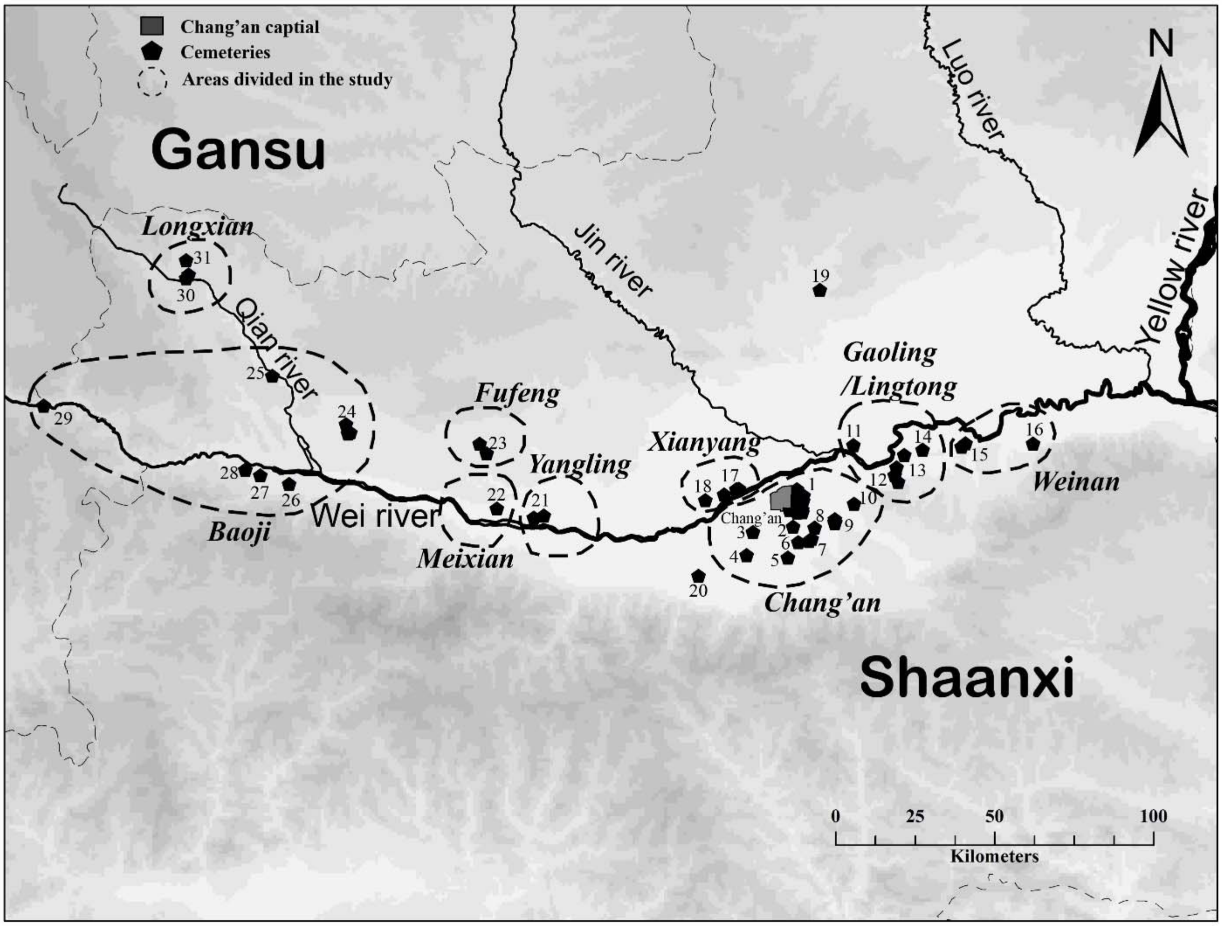

Figure 8.4 Map of Western Han Cemeteries in the Guanzhong Basin

1 (Cheng, et al. 1992a, b; Han and Cheng 1991, 1992; Shaanxi 1987, 2003c, 2006b; Sun and Zhong 2001; Wang and Kong 1987; Xi'an & Zhengzhou 2004a; Xi'an 1997a, 1998, 1999; Zhongguo 1991); 2 (Xi'an 1997b); 3 (Xi'an & Zhengzhou 2004a); 4 (Xi'an 2009); 5 (Shaanxi 2001); 6 (Xi'an & Zhengzhou 2004a); 7 (Xi'an & Zhengzhou 2004a); 8 (Xi'an 2004b); 9 (Shaanxi 2003a); 10 (Zhang 1959); 11 (Shaanxi 2004a); 12 (Shaanxi 1989; Wang 2004); 13[105]; 14 (Shaanxi 2004c); 15 (Cui 1992; Cui and Wang 1998); 16 (Xibei 1989); 17 (Xianyang 1986; Xianyang 1999, 2004, 2006) ;18 (Xianyang 2000); 19 (Ma 1959); 20 (Gao 1980); 21 (Gao and Zao 1996; Xianyang 1996); 22 (Shaanxi & Baoji 1989); 23 (Shaanxi 2010; Zhouyuan 2001); 24 (Shaanxi et.al 2013; Shaanxi 1986a; Shaanxi 1980; Shang and Zhao 1986); 25 (Wang 1975); 26 (Shaanxi & Baoji 2013); 27 (Zhang 1987); 28 (Shaanxi & Baoji 2012); 29 (Shaanxi 2006a); 30 (Baoji 2002; Shaanxi 1999) 31 (Tian and Yang 1998)

According to Hirth (1998), if most individuals are able to engage in market activities, each household—the best archaeological unit for the identification of the traces of market (Hirth 1993)—has the same opportunities to access the same assemblage of artifacts. Archaeologically,

[105] The cemetery information is offered by my collaborator Yang Qihuang in the Shaanxi Provincial Institute of Archaeology.

the inventories of artifacts which are procured through marketplace-exchange would be more or less similar between elite and ordinary households. Although Michael Smith (1998)—another key figure in the study of ancient market economy in Mesoamerica—reminds us that the variation of purchase abilities should be taken into consideration, he still agrees with Hirth's (1998) basic assumption that marketplace exchange will not render the inventory of artifacts exclusively associated with elites in archaeological contexts and generate an undifferentiated pattern in the assemblage of commodities across the landscape.

In order to apply Hirth's heuristic tool in analyzing iron artifacts, I slightly modify Hirth's approaches. Hirth advocates for examining the assemblages and frequency of daily-used objects across the elite and commoners' residential context as follows. Since the residential contexts in the Basin that have been published usually are related to palaces or royal architectures, this study will only focus on tombs as they are the only direct evidence that allows us to evaluate the impacts of commodity economies among commoners. Furthermore, in this research I want to focus particularly on the correlation between the distance to the capital and the percentage of iron goods buried in an area. If my suggestion in Chapter 4 is corrected, Chang'an should be the transportation center for iron resources, and resources from the eastern part of the Empire must pass through Chang'an in order to continue the transportation process. It also goes without saying that, during the Han period, the identities of medium or small scale burials were highly heterogeneous; they would include merchants, craft workers, farmers, bound servants, scholars, and even officials. But it is impossible to differentiate different groups of individuals further. Except for the very exceptional cases where the occupants were buried with a wide range of tools and even models for making exotic bronzes (e.g., Shaanxi 2008a and see related discussion in

Linduff 2009), this study views them as "commoners" in general with similar purchasing power and accessibility to iron goods.

The issue of representative ratio of iron products in burial contexts has been caught attention and caused a large debate among several scholars (Barnard 1978-79; Keightley 1976; Trousdale 1977) before[106]. But as Guanzhong is not only a politically but culturally unique region, I assume "cultural preference"—i.e., that certain types of products were selected for burial to reprsent occupants' identity regardless of any economic factors and accessibility from exchange market—was impacting all data equally. The study above has shown that the assemblage of iron objects is relatively similar across the region. Ring-pommel knives, swords, and caldrons, in general, are the three most common types of objects at each cemetery. Other types of iron tools, especially agricultural tools, were rarely found in tombs, unless occupants were carpenters, smiths, or bronze workers, who might use iron tools to indicate their special identities (Lam TBD). In other words, even though results of comparative study reflect cultural choices or preferences to a certain extent, the differences in distributional patterns, if they can be identified, between these areas should not be entirely or predominately skewed by funeral customs. Instead, the distribution pattern should indicate some meaningful aspects of the transportation and market exchange system. If iron objects were procured through market exchange, and the government did not restrict the flows of these products, the assemblages of iron artifacts will be similar across different cemeteries or areas, and the converse should also be true.

[106] It has become more and more obvious that the major concern in Barnard, Trousdale, and Keightley's debate, in fact, ignores mortuary practices. Since voluminous data have been published after the 1970's, it already become a common sense that in Chu tombs burying bronze weapons was a common practice—almost every male member would be buried with a bronze sword—while this custom was not commonly practiced in the Qin state. Therefore, it appears to be misleading to discuss the technology and popularity of a technology in the society only based on one single line of evidence from mortuary data.

In the statistic study below, I only calculate the “frequency” of burying certain types of items in burials. The exact numbers of each iron item were not taken into consideration here. Since this study only investigates the accessibility of iron products, the frequency of burials containing certain types of goods can help reduce the impacts of hierarchy or differentiation of social status in the results. Meanwhile, since the evidence of market exchange did undoubtedly exist, this statistical approach tries to target at the governmental involvement in exchange, or the role the political center and production centers played in the mechanism of distribution by focuing on the difference between the core and periphery.

To facilitate the discussion, I will break down question *#2* raised at the beginning of this chapter and explain how the comparison and statistical study would help address this issue.

1) If Taicheng could produce tools that were made by hammering or forging, would the frequency of this type of artifacts be different from the cemeteries that without any identified iron foundry nearby the site?

The first question focuses on distribution from a local perspective. To be more specific, if small foundries like Taicheng only focused on consumers in their neighborhood, would these foundries be efficient enough to produce surplus goods and trade them to other counties? As we allured to before, in the entire Guanzhong area, Han iron foundries were small and unevenly found; in many counties, there was even no evidence related to any systematic production of iron yet discovered. Therefore, if the market was relatively undeveloped, and the frequency of a type of goods would be dependent on the distance to the production center in a less-developed market setting, the Taicheng assemblage should show a highly frequency in items that would have been produced by the foundry than most other areas without clear evidence of iron production.

2) If Chang'an played a role as a redistribution or production center as most capital walled-towns did during the Bronze Age, would the frequency of iron objects—including both iron tools that were made by hammering and other iron vessels—from commoners' cemeteries be higher than that in other cemeteries?

If the residence at Chang'an had better access to small tools, would this issue be reflected in the assemblages of iron tools? To address this issue, I compare the data from Taicheng as well as other cemeteries to data in the area of the Chang'an capital. Again, if the market system was not relatively developed, the percentage of tombs containing iron goods in Chang'an area should be higher than those in other counties. In order to draw a more robust conclusion, I will investigate the pattern of bronze goods (8.3.2) alongside iron objects (8.3.1) in the Chang'an and other areas. As I will explain below, evidence associated with bronze production was even fewer in the Guanzhong Basin; the acquisition of bronze objects had to rely entirely on exchange and transportation. If the allocation patterns indicate that the percentage of iron and bronze objects buried in the capital is not significantly higher than that in other areas, a full and integrated market system should exist in the Guanzhong Basin during the Western Han period.

8.3.1 Iron products

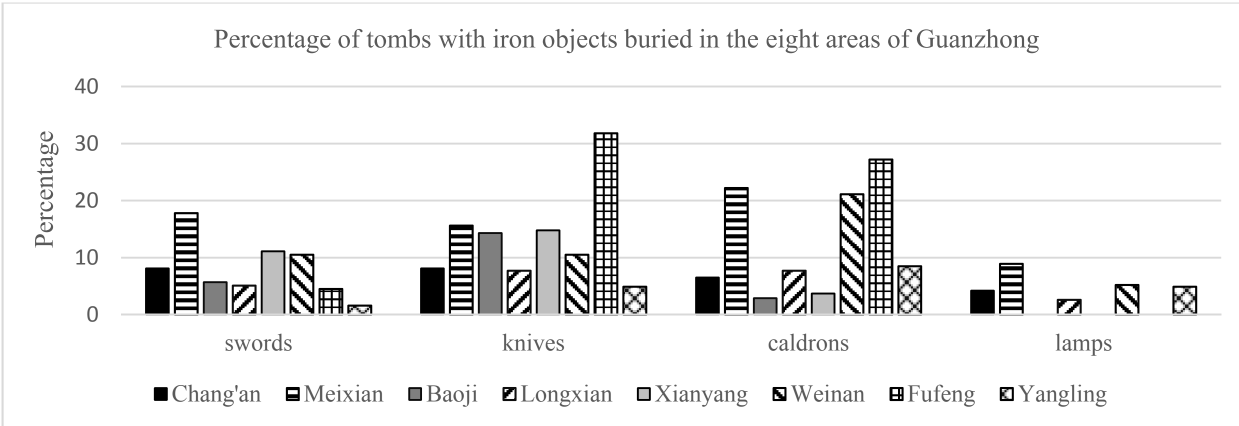

Figure 8.5 Regional frequencies of iron objects (Western Han)

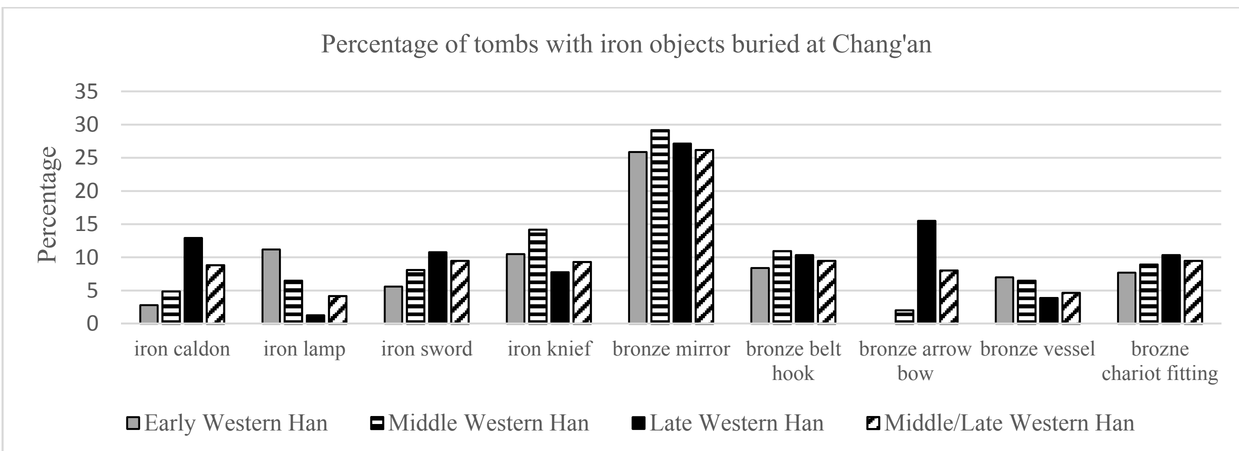

Figure 8.6 Burying percentage of iron and bronze objects in Chang’an

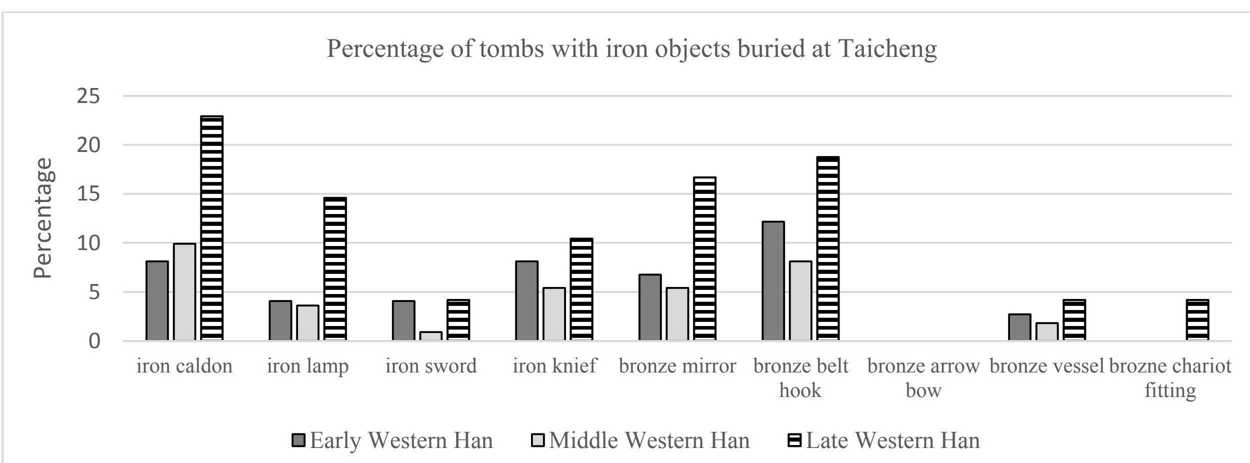

Figure 8.7 Burying percentage of iron and bronze objects at the Taicheng cemetery

Since the dataset from the Chang'an area is large enough to generate statistically meaningful result, here I will first introduce the assemblage of iron objects in the capital area. The frequencies of the four major types of artifacts (Figure 8.6) are relatively low in all published Western Han tombs; usually lower than 10% of burials included any of these types of iron objects; the ubiquities of the four types of artifacts are just 8.1%, 8.1%, 6.5%, and 4.2% respectively. These frequencies also witness certain chronological changes. Only the frequency of iron knives is stable and between 10~15% throughout the entire Western Han period. For iron swords and cauldrons, their frequencies seem to rise from the Early towards the Late Western Han periods. In contrast, iron lamps appeared to be gradually out of favor during the Middle and Late Western Han periods.

Because the Taicheng cemetery provides the largest set of funeral data outside the Chang'an area (295 tombs), the burial dataset from the Yangling area can allow us to investigate chronological changes of assemblages. In terms of the frequencies of iron objects, quite surprisingly, the numbers are very low in comparison with the Chang'an area (Figure 8.7). Among the four major types of iron artifacts, the frequency of burying caldrons is the highest; about 8.5% of tombs containing this type of artifacts. But for iron lamps and knives, the percentages are just 4.9% respectively. The percentage of iron swords is even as low as 1.6%. The percentages of burials containing other iron weapons or tools (e.g., spearheads, *ji*, and spades) were also below 2%. Although certain numbers of iron knives and tools might have been manufactured by the Taicheng foundry, the proximity to the iron foundry did not lead to large percentages of these objects in the assemblages. The reason that these occupants (or their relatives) were not willing to bury more iron tools in tombs is yet to be clear, but the foundry did not seem to manufacture enough surpluses to allowed occupants to bury iron objects as frequently as other areas.

After dividing the data into phases, some chronological developments can be identified even though they are not very similar to those in Chang'an. For iron swords and knives, the percentages between the three phases are obscure; no clear changes or patterns can be identified. The percentage of iron knives is about 5~10% between the three phases, and the percentages of swords are all below 5%. But for iron caldrons and lamps, the percentages from the Early to the Middle Western Han period (caldrons 22% and lamps 15%) increased by about 3~4 times, perhaps indicating a sudden increase in the accessibility to certain types of objects in the market.

In other areas, published data are much fewer than the two areas mentioned above (Table 8.1). Not only are numbers incomparable but also the parts that have been published are highly selective and biased. Furthermore, only tombs that were preserved relatively well or contained rich assemblages of goods received attentions in publication. Also, in terms of frequencies in each phase, not every area has enough samples representing the three phases. For instance, in Weinan and Longxiang, all published data only date to the Middle and Late Western Han period. For this situation, I will just discuss the percentages of all Western Han tombs as a whole from the same area or same cemeteries.

In Figure 8.5, I show the percentages of the four major types of iron artifacts—which represent a rather mosaic scenario—between these areas. In some regions, the high percentages of burials containing certain types of iron objects are relatively high. For instance, the percentage of burying iron caldrons seems to particularly high in Meixian (data primarily from a cemetery called Changxing 常兴). Also, burials from Fufeng (samples primarily from Zhibai) also show high percentages with iron knives and caldrons. In addition, the ubiquity of iron swords and knives in Yangling appears to be the lowest in comparison with other areas. In general, data do not support the idea that occupants in the Chang'an area had a higher chance to bury iron objects because they had more access to these resources or were more adjacent to the transportation center. Nor do data support the viewpoint that the burials in counties or settlements with clear evidence of iron production show a higher ubiquity of iron objects in tombs. To better test this idea, I aggregate all iron items into the column "iron objects" to calculate the percentage of tombs in each area burying at least one type of iron goods. The result clearly demonstrates that there is no correlation between the distance to the capital and the percentage of containing iron objects in tombs (Figure 8.9).

The analyses in the above sections and previous Chapters have already pointed out that the procurement of substantial numbers of iron objects in each local center had to depending on the support through the transportation system centered in or radiated from Chang'an. In terms of the iron assemblage in each area, the allocation patterns support an active role of market system in distributing iron tools throughout the entire political center. Through a strong influence of the market system in the transportation of products, the frequency of iron vessels, iron tools, and iron weapons buried in tombs seems to follow an idealized market-dominated scenario: the frequency that certain types of daily products in archaeological contexts did not drop or decrease alongside the increase in the distance to the capital center. Without the market system, residents in Longxian or Baoji would be able to get access to the similar iron assemblages as residents in Chang'an. In other words, distance to the production or transportation center was not the key factor in shaping the allocation or distribution pattern of iron objects. Furthermore, local iron foundries might have facilitated the circulation and transportation of iron products through production and recycling. These small production centers focused on items that were not fully covered by the market network, and, eventually, the local production and market exchange seems to have played their roles in the economic system at the same time.

Nonetheless, it is very challenging to understand fully the variations between different areas illustrated by the mosaic pattern given the limited information presented here. As I discussed earlier, this mosaic pattern might have been due to lots of different factors. The selection of data to publish or even the selection in areas for excavation would impact these calculations and therefore increase biases in the result. Also, it is yet to be clear whether differences in social status in reality would lead to any difference in the percentages of iron goods buried in tombs. For instance, if data from Chang'an were more present among the lower stratum of Chang'an residents, while the tombs in other areas belonged to wealthier members or the upper class (e.g., the case at Zhibai), this scenario could have easily generated a pattern in burial data that we observe in the dataset. In short, although all these burials were classified as "commoners' tombs" in the study, the occupants of these tombs might, in fact, include a wide variety of different economic statuses. Forces that contributed to the percentages of iron objects in tombs by no means came only from the market economy. Since this study is the pioneering research in this regard, I hope that future archaeological works can help further address to what extent these factors contributed together to skewing the percentage in burial contexts.

8.3.2 Bronze products

To further address the allocation pattern, this section continues to focus on the same dataset but shift to the assemblages of bronze objects. Bronze objects from the Guanzhong area usually cover categories different from iron objects. The assemblage of bronzes include mirrors, belt-hooks, coffin-decorations, chariot-fittings, bronze vessels (including *ding* 鼎 tripods, *feng* 钫 jars, and *xi* 洗 basins), weapons (e.g., crossbows), knives and other tools, seals, coffin decorations, and, most importantly, coins. But in this section, the allocation pattern and percentage of bronze coins will not be taken into consideration because, unlike other items, bronze coins sometimes served as heirlooms passed down several generations before they were eventually buried. In comparison with iron, bronze objects are more likely to be targets of looters and less likely to be left-overs after looting. It is, therefore, necessary to bear in mind that the assemblage and allocation pattern of bronze objects might be more prone to the impacts of later looting.

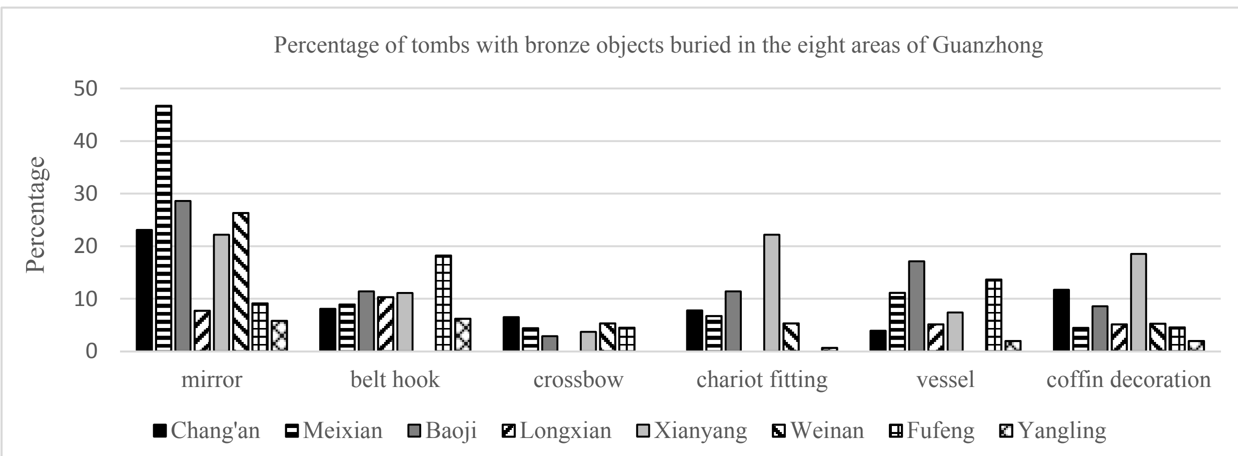

Figure 8.8 Regional frequencies of bronze objects (Western Han)

In the Guanzhong Basin, bronze objects include both local products and imported items, but the procurement and consumption of bronze items might have had to rely more heavily on external centers and the exchange network. For instance, evidence showing the production of bronze mirrors—the most common type of bronze in the assemblage—was only found in Linzi, Shandong, so far. Since the amount of manufacturing waste demonstrate that the production was undertaken on a very large scale, some scholars suggest that Linzhi was the major production center of bronze mirrors for the entire Empire (Yang, et al. 2013). Also, the bone tablets excavated from palaces in Chang'an shows that bronze weapons, especially crossbows were primarily manufactured by local workshops controlled by the government (or the so-called *san gongguan* 三工官—three workshop offices) outside the basin (Liu and Zhang 2006). For bronze vessels, inscriptions on bronzes show that vessels were manufactured by workshops[107] that were directly controlled by the central governments (Wu 2007) but were not necessarily inside the capital. For instance, bronze vessels manufactured by the Western Workshop of the Shu Commandery were distributed throughout the eastern part of the Empire (Barbieri-Low 2007; Wu 2014). In terms of the bronze belt hooks and chariot fittings, some might have been manufactured by a local workshop controlled by the local government. In the northwestern corner of Chang'an, molds for casting these two items were found. Therefore, the bronze objects found from the Han tombs were either produced by the workshops directly controlled by the central government adjacent to the capital or outside the Guanzhong Basin. But except for the coin mints at Shanlinyuan (Xi'an 2004a), no evidence shows bronze production was organized on a large scale in any areas within the entire region.

Since the majority of these bronze assemblages might not have been produced by local production center or even workshops inside the basin, the allocation patterns of these items should be similar to those of iron objects if market exchange system did play a key role in the exchange and transportation. If a full-fledged market system was responsible for distributing iron products from production sites to different local centers, bronze products might be distributed by the same mechanism and represent similar distributional patterns in archaeological contexts. For

[107] As Wu (2007) argues, the production system for bronze vessels should consist of two types of workshops: those controlled by the government and those owned by local rulers or merchants. But after Emperor Wu, bronzes produced by the second type of workshops disappeared and were replaced by the first type.

this reason, I adopt statistical analysis of bronze objects to help further evaluate the transportation of iron objects.

According to the result, in the Chang'an region 23% of tombs were buried with bronze mirrors, this percentage seems to be higher than that of any iron products. Coffin decorations are the second most common bronze objects in tombs. About 11.7% yielded this type of artifacts. Belt-hooks, weapons (primarily crossbows), and chariot-fittings were also common in the burial assemblage with percentage of 8.1%, 6.5%, and 7.8% respectively. The ubiquity of vessels is the lowest among these categories. Only 3.9% of tombs yielded bronze vessels. When dividing the data according to phases, mirrors, belt-hooks, vessels, and chariot fittings do not seem to present a remarkable chronological change in terms of their ubiquity. But the percentage of weapons during the Early Western Han period is below 5%, while it jumped to 20% during the Middle Western Han and remains above 15% throughout the entire Western Han period.

Quite interestingly, the ubiquity of burying bronze objects in Yangling is also very low, similar to the pattern of iron objects. The percentage of mirrors is only 5.8%. Coffin decorations, chariot fittings, vessels, and weapons are even below 2%. The percentage of belt hooks is 6.2%, but it is the highest among all bronze categories. In the chronological comparison, the three phases seems to show a significant increase in the percentage. For instance, the percentage of tombs containing mirrors increased by three times during the third phase relative to the first and second phases. The percentage of burials with belt-hooks during the third phase is also higher than those of the preceding phases. Therefore, the patterns suggest that the residents in Yangling either had a lower economic rank than residents in general in Chang'an or had more limited access to bronze products in general.

The frequencies of bronze objects in other areas did not present a meaningful pattern corresponding to the distance to Chang'an (Figure 8.8). For instance, in Xianyang, Baoji, and Meixian, the percentages of burying bronze mirrors among all Western Han tombs are more or less similar to that in Chang'an. In Meixian, the percentage of burying mirrors is as high as 45%, which is even significantly higher than the percentage in the capital. Also, the percentages of burying bronze crossbows, belt hooks, and chariot fittings are relatively similar to the entire Guanzhong Basin.

But three areas: Longxian, Fufeng, and Weinan should be of particular note here. In Longxian, almost no bronze weapons (crossbows) and chariot fittings were identified. The ubiquity of mirror in tombs is even as low as 8%. In the Fufeng area, the percentage of mirrors in tombs is also very low, and no chariot-fittings were found in tombs. These two patterns are both similar to the scenario in Yangling. In the Weinan area, no bronze vessels or belt hooks were found in reported tombs. Even though archaeological evidence did not clearly show the distance to Chang'an corresonds to the changes in allocation pattern of bronze objects, the study of bronzes seems to suggest that Chang'an generally had more access to common bronze products such as bronze mirror, belt hooks, and crossbows. The transportation system of bronze objects might still be driven primarily by market exchange and trading, but there might be two different processes of iron and bronze objects regarding the details of exchange mechanisms

First, areas further away from the capital have more limited access to certain type of bronze object (e.g., mirror). For instance, percentages of bronze mirrors are relatively low in Longxian, Fufeng, and Yangling, while mirrors are quite common in Chang'an.

Second, certain categories that are related to social ranks and official titles (e.g., chariot fittings) were absent or relatively rare in the assemblages in comparison to Chang'an. Also, the ubiquity of burying bronze vessels tends to be fluctuated between Xianyang and Meixian.

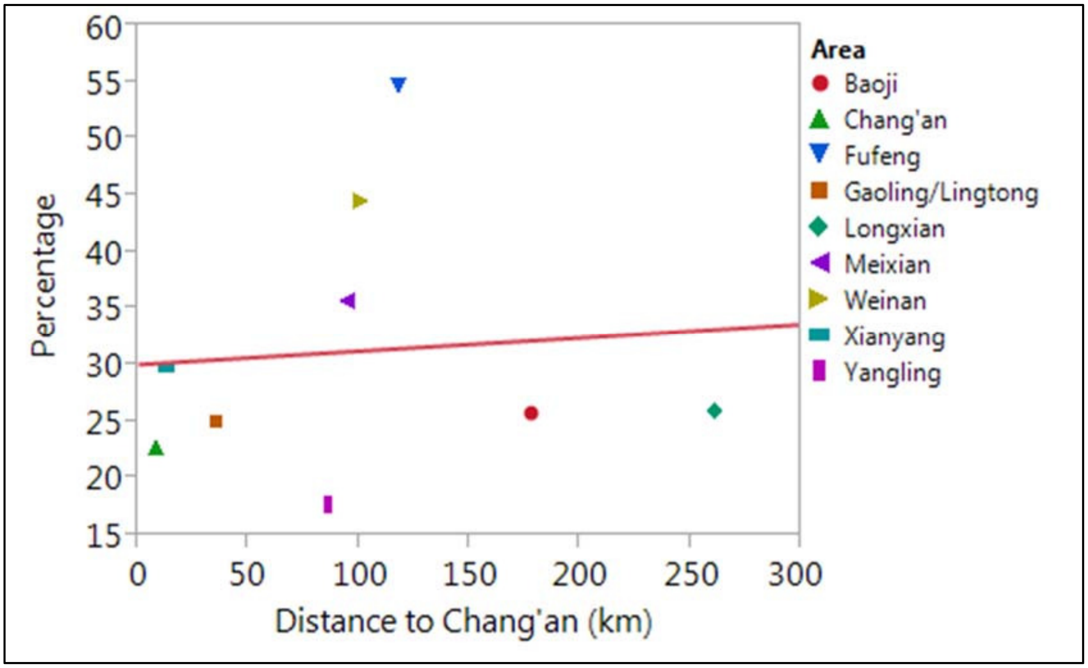

Figure 8.9 Correlation between the percentage of tombs containing iron objects in different areas and their distance to Chang'an

(Y axis: percentage of tombs in an area burying with one of the four types of iron objects
X axis: distance of an area to Chang'an city)

Table 8.1 Numbers of Western Han tombs collected in the Guanzhong Basin

Chang'an	Xianyang	Gaoling/Lingtong	Yangling	Fufeng	Meixian	Weinan	Baoji	Longxian
1041	27	30	306	22	45	19	35	39

These two patterns seem to suggest that the market network of bronzes were more loosely connected the capital and small centers together. As a result, small (e.g., Taicheng) or distant areas or centers might be prone to have less access to bronze artifacts. This phenomenon may be attributed to the fact that, in comparison with iron items, bronze objects were less likely to be manufactured by the local foundries[108]; workshops controlled by the central government outside the capital might be responsible for manufacturing the majority of these bronze objects. In addition, during the implementation of monopoly policies, the private production of bronzes was particularly banned for the sake of preventing the private minting of coins. But members from certain areas could still have the same access to certain categories of iron items regardless of social ranks and economic status.

In comparison with bronze objects, the transportation of iron might be more intense and supply objects more sufficiently to local centers. Given the limitation in the technology of transportation and spread of information—which was always the case in ancient economic system, transporting large amounts of iron agricultural implements might generate an extremely high cost and reduce the flexibility of the production system for the need of consumers. In the social setting of Early China—and similar ancient societies as well—a complete reliance on market processes to procure or trade daily necessities would be almost impossible. Thus, setting up small iron foundries in the entire Guanzhong Basin might have been an essential approach for the Han government to overcoming challenges in order to make a market system functional.

By taking the factor of transportation into consideration, I propose that this type of foundry might not be labeled as a "commodity workshop". For one thing, the Taicheng foundry and other small workshops as well probably did not support goods or interact with customers outside the county because of its small scale. It is important to note that the ubiquity of iron in the assemblages in Yangling is usually lower than other centers as well as the capital. Were these foundries manufacturing a significant amount of surplus, would the percentages of these items in

[108] Bronze products might have been manufactured by some co-crafted center (e.g., Yaoshan), but they were small in scale and were rarely found in Guanzhong.

Yangling be much higher? Related to the issue, the study in Chapter 7 also demonstrates that workers tried to manufacture in an efficient manner, but evidence does not suggest that every procedure is steam-lined and highly standardized. Workers might have had different technical customs and preference in the casting processes since factors such as "market competition" did not exist (at least not to a significant extent) in the local production system.

Adopting Minc's frameworks, the case study shows the market system in the Han dynasty might be the middle ground between a "dendritic market" and an "integrated market". Goods and resources that were drawn from the eastern part of the empire were transported to the capital first. Craft production of bronzes and some iron items were controlled by the governmental workshop nearby the capital. Thus, residents in the Chang'an area might have more access to certain types of commodities than commoners in other counties regardless of their social status. But each market zone in these counties was not entirely dominated by only the single center in Chang'an. The establishment of small iron foundries in county-level settlements, nonetheless, might have played a key role in fueling the movement of goods. The products of these foundries complemented the market network by providing daily goods that otherwise could not be produced on a large scale. In addition, the small foundries also help fulfill the function of an entire network by allowing the residents to get more access to goods in places that were not sufficiently covered by the market network.

8.4 The Development of the Market System in the Guanzhong Basin

After addressing the nature of the Taicheng iron foundry and the market system behind the iron foundry in the Han capital area, a critical question that immediately follows is how to fit the production of iron commodities into the historical context of the development of a commodity economy. To put it another way: if we try to address how iron commodities contributed to the development of the commodity economy through this case study, we need to further address what the commodity system predating the Han period looked like in the same geological area. The final section in this chapter tries to shed light on the relationships between political change and the development of the market system by focusing on the iron assemblages in Warring States and Qin periods burials.

From the textual standpoint, the Qin state might lag behind in market or commercial development during the Warring States period. The "market system" was initially established by Duke Xian around 378 BC[109]. Alongside the rapid expansion and eastward conquest, the Qin state might at this point start to establish the market network that could facilitate the movement of goods within its territory and connect various centers with various degrees of regional integration. But since Lord Shang's reform advocated the agricultural development by depressing the development of commercial activities[110], to what extent the market economy was the major driving force in the Imperial economy was debatable in literature (e.g., Si 2002). Archaeological records provide another important line of evidence for resolving this debate. Emura (1995) argues that the development of a commodity economy in the Central Plains might be much more advanced than other states, especially Qin since the density of discovered walled-towns in the former region is the highest than all other regions in archaeological works.

During the Warring States period, evidence of iron production was identified in the capital area in Xianyang (Shaanxi 2004b). In other local centers, however, evidence of iron production is very rare. A bronze industry should exist outside the capital area, at least in Yong (Baoji)

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[109] *Shiji* 6. 289.

[110] *The Book of Lord Shang,* "Kenling 墾令" 1.2:9.

(Tian 2013). For this reason, data of the Warring States period could serve as an ideal counterpart to test the theoretical model in interpreting the allocation patterns. If the commodity economy was still at its primitive stage during the Warring States period, the allocation pattern of iron as well as bronze objects should present an image relatively different from the scenario in the Western Han period.

For this reason, I collected all published Qin tombs data and employ approaches mentioned above to investigate the allocation patterns (Figure 8.10; Table 8.2). For the chronology of tombs, I adopt the conclusions in the site reports and refer to previous synthetic studies on this issue (e.g., Teng 2002). Data dating to or predating the Middle Warring Stats will be of particular interest in the study. Although cast iron technology arrived in the Qin states about the transition between the Springs and Autumns and Warring States period, evidence showing large scale iron production (i.e., that cast iron objects frequently appear in tombs) did not emerge until the Middle Warring States period. In addition, in order to make the study comparable, I try to divide the basin into several areas similar to the process of Western Han data but with several minor changes according to local situations. In the study below, I also focus on iron and bronze objects for the purpose of comparison. I will compare the allocation patterns of iron/bronze knives as well as iron/bronze belt-hooks. These four items usually are the most common metal objects in Qin tombs.

8.4.1 Iron objects

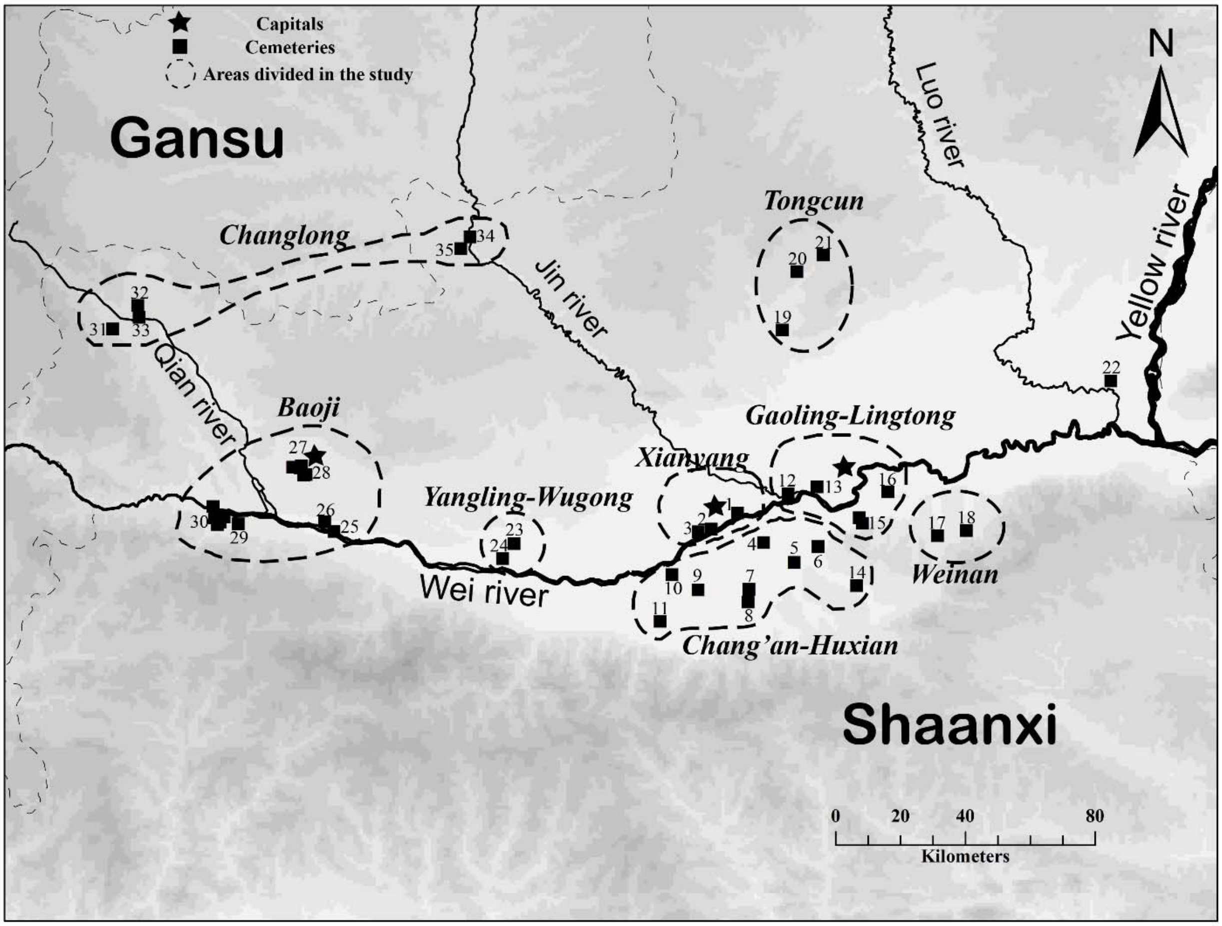

Figure 8.10 Cemeteries of Eastern Zhou cemeteries of the Qin State in Guanzhong basin

1 (Shaanxi 2004b) 2 (Xianyang 2005) 3 (Xianyang 1998) 4 (Shaanxi 2006c, 2008a) 5 (Jin 1957) 6 (Zhang 1959) 7 (Wang 1994) 8 (Xi'an 2004c) 9 (Zhongguo 1962) 10 (Shaanxi 1975) 11 (Cao 1989) 12 (Shaanxi 2003b) 13 (Shaanxi 2004a) 14 (Zhongguo 1988) 15 (Qinyong 1980; Shihuangling 1983) 16 (Shaanxi 1998b) 17 (Shaanxi & Weinan 2011) 18 (Shaanxi & Qinshihuang 2006) 19 (Ma 1959) 20 (Shaanxi 1986b) 21 (Shaanxi & Beijing 1987) 22 (Shaanxi & Dali 1978) 23 (Gao and Zao 1996; Xianyang 1996; Xianyang 1992) 24 (Zhongguo 1996) 25 (Shaanxi 1965) 26 (Baoji & Baoji 1980) 27 (Shaanxi et.al 2013; Shaanxi 1991; Yongcheng 1985) 28 (Shaanxi 1986a; Shaanxi 1980; Shaanxi 1986c; Shang and Zhao 1986; Yongchang 1986; Yongcheng 1980) 29 (Su 1984) 30 (Baoji & Baoji 1979; Baoji 1991; Tian and Lei 1993; Zhao and Liu 1963) 31 (Baoji & Longxian 2001) 32 (Gao and Wang 1988) 33 (Shaanxi 1998a) 34 (Shaanxi 1985b) 35 (Zhongguo 2007)

In Qin tombs, the assemblage of iron objects usually includes knives, belt hooks, and decorations. In comparison with the Han period, iron caldrons (or vessels in general) and long swords were rarely found in Qin tombs (Bai 2005; Teng 1993:115, 1995). Iron was not used in the production of belt hooks anymore during the Han period. These differences might be related to both technological development (refined pig iron) and changes in funeral practices focusing more on daily-use vessels in funeral contexts.

Data from the Baoji area shows that the cast iron industry might arrived in the Qin state as early as the Late Springs and Autumns period (Shaanxi 1985a). But the emergence of iron knives in tombs started in the Middle Warring States period. In Xianyang, the capital of the Qin state after 300 BCE, about 9.5% of tombs included iron knives (Figure 8.11). This number, in fact, is already not differetn from the percentage in the Western Han period. Perhaps putting iron knives in burials were not emphasized in funeral rituals from the Warring States to the Han period. But the inter-site comparison shows an intriguing picture about the allocation pattern. The percentage of iron knives in Xianyang is higher than those in Yangling, Changlong, Gaoling, Weinan, and even Baoji. The percentage in Chang'an is very close to Xianyang. But Chang'an already gained its important role during the Late Warring States period as it is adjacent to Xianyang, and residents might not find it very difficult to obtain goods produced in Xianyang.

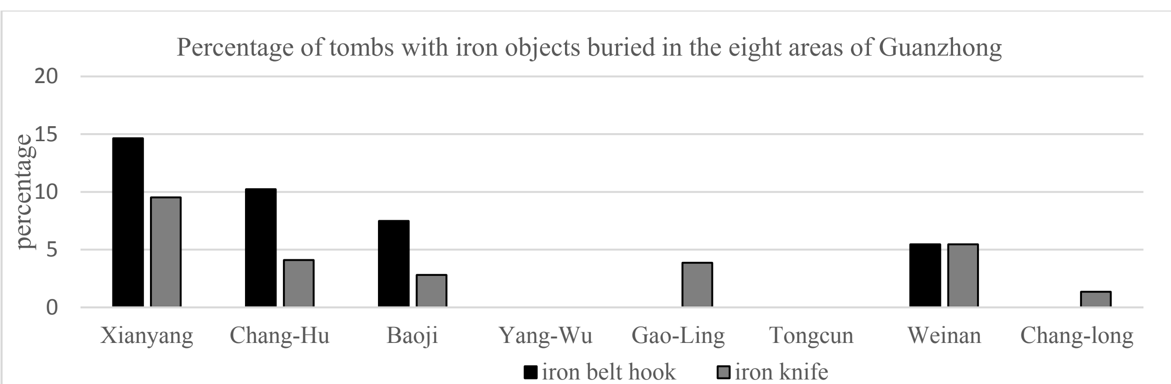

Figure 8.11 Percentage of iron items in Warring States cemeteries

In comparison with iron knives, iron belt-hooks were more popular in burial assemblages. About 14.7% of tombs in Xianyang contain at least one piece of iron belt-hook. Iron belt-hooks were also more commonly buried in other areas. Similar to the pattern of iron knives, the percentage in Xianyang appears to significantly higher than those in Yangling, Changlong, Gaoling, Weinan, and Baoji. Iron knives and belt hooks were absent in the assemblage in Changlong[111], the area furthest away from Xianyang. But in Chang'an, the area adjacent to Xianyang, the percentage of iron knives and belt hooks is particularly high in comparison to other areas. Thus, this allocation pattern clearly shows that the frequency of iron knives and belt hooks is intimately associated with the proximity to the capital. In tombs that are relatively the same size and buried with similar assemblages of burial goods, residents in the capital area might have had more chances to be buried with iron knives and belt hooks (Figure 8.13) than other areas. This discrepancy seems to suggest a primitive development of the market economy in the Warring States period.

8.4.2 Bronze objects (bronze knives and belt hooks)

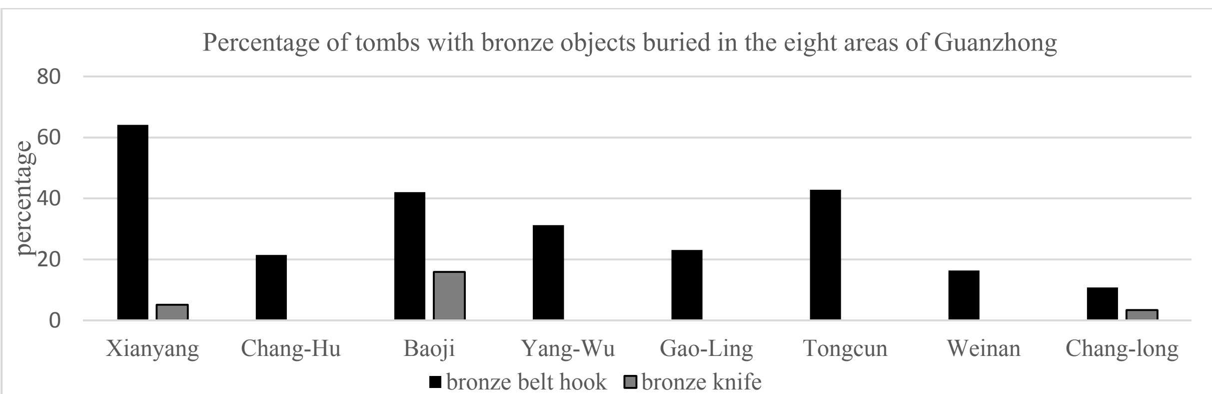

Figure 8.12 Percentage of bronze items in Warring States cemeteries

The assemblage of bronze objects in Qin tombs includes knives, belt-hooks, mirrors, weapons, and ritual vessels. Bronze knives were often found in elite tombs before the Warring-States period, but only starting in the Warring States period did bronze knives become fully accessible to commoners as daily-use products and burial goods. Data in Xianyang as well as in

[111] Only three pieces of iron caldrons were reported from the Dianzi cemetery.

Chang'an also show that the percentage of tombs burying knives gradually declined towards the Han period (Figure 8.12). This tendency might be related to the appearance of iron knives as a better alternative option and replacement of bronze knives in the assemblage.

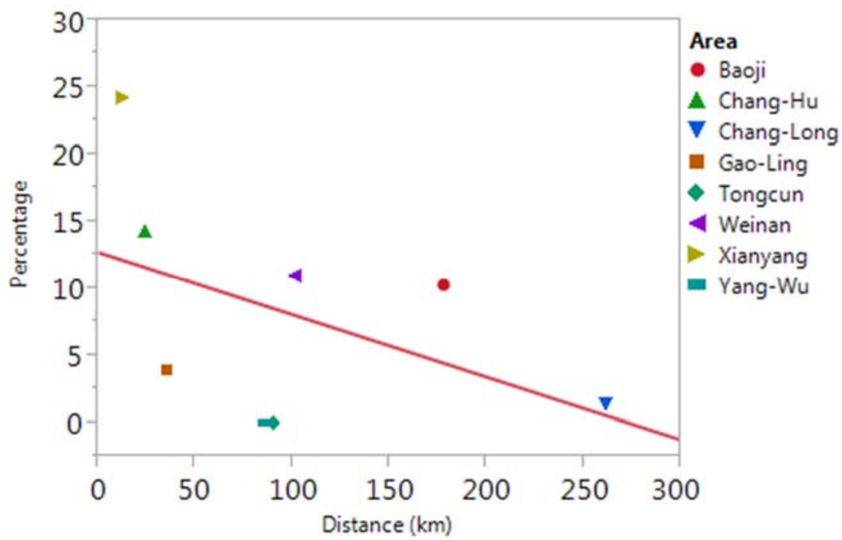

Figure 8.13 Correlation between the percentage of tombs containing iron objects in different areas and their distance to Xianyang

(Y axis: percentage of tombs in an area burying with one of the two types of iron objects
X axis: distance of an area to Xianyang)

Table 8.2 Numbers of Qin tombs collected in the Guanzhong Basin

Xianyang	Chang-Hu	Baoji	Yang-Wu	Gao-Ling	Tongcun	Weinan	Chang-Long
273	391	107	16	26	7	55	148

The inter-site comparison also demonstrates a distinctive pattern different from iron objects (Figure 8.12). Bronze knives were almost absent in Chang'an burials. Also, the percentage in Xianyang, in general, is relatively low and even lower than the percentage in Baoji. Furthermore, in the Changlong area, small amounts of bronze knives were identified. Therefore, the percentage of bronze knives was subject to two factors at the same time. First, bronze knives were gradually replaced by their iron counterpart and became significantly withdrawn in the assemblage. Second, the allocation pattern of these objects might have been skewed by local production and did not clearly show a pattern that correlates with distance to the capital. As a result, the difference between the center and peripheral areas is not remarkable in this case.

Bronze belt-hooks were probably the most common type of funeral goods in Qin burials. The earliest bronze belt-hooks in burials appeared about the late Springs and Autumns period. The percentage gradually increased and eventually rose to 50~60% in Xianyang during the Late Warring States period. In constrast with the development of bronze belt-hooks in the assemblages, the appearance of iron belt-hooks might be a solution of using an alternative but cheaper material to supplement the production and meet the increasingly enlarging social demands for this type of products.

Similar to the inter-site patterns of their iron counterparts, the percentage of bronze belt-hooks in Xianyang is significantly higher than in other areas. The ubiquity is even three times that in Chang'an. Also, even though bronze belt-hooks were common in tombs nearby Yongcheng, the highest percentage during the Early and Middle Warring States was about 38%. The bronze industry for producing bronze belt-hooks in Xianyang might have been much larger than other workshops in preceding capitals. In Changlong and Weinan, there are also about 10% of tombs with bronze belt-hooks. The social demands for belt hooks might be very large, and the preexisting bronze foundries might help manufacture bronze belt-hooks in order to meet the ever-increasing social needs. Since the social demands on bronze knives rapidly decreased during the Warring States period because of the replacement by their iron counterparts, most residents did not have bronze knives available on the market to be used as burial goods.

Summary

The comparison between iron and bronze objects during the Warring States and Qin periods shows that tombs in the capital area (Xianyang) yielded iron belt-hooks, iron knives, and bronze belt-hooks more frequently than tombs in other areas. Especially in Chang-Long—the area furthest away from the capital, the percentages of the three categories are usually the lowest. Other areas between the capital and Chang-Long have the percentages in the middle ground. But these percentages do not entirely correlate with distance to the capital. In each category of objects, there are some outliers, probably related to factors such as sample sizes, preservation in archaeological contexts, or personal selection of certain items in burials. The economic status might be another key factor, but as previous studies on Qin burials point out (Falkenhausen 2004; Shelach and Pines 2006; Teng 2013; Teng 2002), the traditional social hierarchy no longer emphasized burial practices after Lord Shang's reform. In burial context, the differentiation of social status became very vague and unrecognizable. As such, I suggest that economic status might not be a dominant factor in the frequencies of metal objects. That said, the accessibility of iron daily-use objects in different centers should reflect more on the transportation system and market network rather than the social or economic rankings in Qin society.

The striking difference between the capital and Chang-Long suggests that, given the preliminary development of market system in the Warring States period, residents in distant counties or areas had more limited access to products manufactured by workshops in the capital area. Although these objects (iron knives and iron belt-hooks) might be considered as "commodities" that were sold on the market, the customers were primarily residents in the same settlement or nearby. Only very few of these items were traded or transported to other parts of the state even in the same geological region. Consequently, the frequencies of these commodities in tombs seem to drop alongside the distance to the capital.

From a quick look at data, the assemblage of iron goods includes iron belt-hooks, knives, and other tools for various purposes across the entire Guanzhong Basin. Based on the assemblage, there are vague differences in the funeral customs of selecting the types of iron or bronze objects to be buried in tombs between these areas. But in terms of the frequencies, burials between the capital and other areas demonstrate a substantial difference, inferring that iron items and other goods that might have been manufactured by capital workshops were not transported outside on a very large scale. Very unlikely a full-blown market exchange system already took place during the Warring States period. By referring to Minc's terminology, a comprehensive "dendritic" market system of metal objects seems to be more applicable to the case of the Qin state in the Warring States period. In other words, even though a market system did exist during the Warring States period, the entire market network was dominated by the capital and subject to the limitation of transportation capacity.

Therefore, there might have been a significant shift in the market system—a shift towards a more systematic and increasing efficient network, between the Qin and Han period in the entire Guanzhong Basin. I disagree with the previous idea in literature and consider the term "commodity economy" might be a misleading theoretical scheme to fully conceptualize the economic system of the Qin state. Even though evdience of ceramic industry shows that "commodity branding" and "private-owned workshops" did emerge in the period (Yuan 1987), the distance that the market network covered and the products traveled was likely very limited, probably not very much extended beyond the capital area. Before the establishment of the Western Han period, iron products that were manufactured by private-owned factories and sold by merchants through a market system might not have been transported to centers such as Longxiang over long distances. Eventually, the "dendritic" market system in the Qin state was not able to effectively integrate all parts of local societies together, since the transportation system still was heavily influenced by factors of distance or the proximity to the production center.

The existence of "dendritic" market networks also indicates that a strong involvement of the governmental control in the industry. According to the Shuifudi Qin bamboo slip records, local county officials needed to identify and recycle corroded iron as well as bronze items owned by the local government each June[112]. In fact, the Qin state was one major consumer of iron products in the society. Since the text implies that the local governors needed to buy iron objects from and to sell to local iron foundries, does this textual record contradict to an allocation pattern that sees the transportation of iron objects as relatively vague and less active in the regional center according to archaeological records? I suspect that this pattern of using small foundries to facilitate the flow and movement of iron objects through a market network might be a relatively late policy to adjust to the administrative needs of the ever-growing empire after the unification. During the Warring States period (or at the very least the last 100 years of the Qin empire), this type of small and local iron foundries might be even rarer than during the Western Han period.

Conclusion

In this chapter, I integrate the analyses of iron objects from both a micro-scale (archaeo-metallurgy) and a macro-scale (spatial allocation patterns) to investigate the market exchange system in the Guanzhong Basin. The combination of analyses on the two scales depicts a more comprehensive image of the structure and development of market system in the Han capital area. The major conclusions are as follows:

112 *Shuifudi*, "Statutes of Currencies", trans.s Hulsewe 1985: A47, p.53.

First, although iron foundries situated in the Guanzhong Basin like Taicheng were small, their role in the market system during the Han period should not be therefore underestimated. Besides casting agricultural implements, these small foundries employed forging and smithing to manufacture iron tools, especially iron ring-pommel knives. Decarburized steel and refined pig iron objects were also found in tombs and foundries dating to the Early Western Han period. The spread and fast adaptation of the new technique provided alternative methods to produce iron objects, especially large-size weapons like iron swords. Therefore, the small iron foundries could have manufactured a wide range of tools employing multiple techniques.

The archaeometallurgical analyses show that the majority of raw materials in the three examined cases came from decarburized steel bars or billets and scrap iron. So far, evidence for the production of this type of iron bars was absent not only at Taicheng but also in the entire Guanzhong area. Either the raw material (iron bars) or the final products must have ben manufactured by foundries outside the Basin. The distribution and consumption of iron commodities in the Guanzhong basin must be situated in a large market network; otherwise foundries like Taicheng alone could never fully explain the discrepancy between the foundry and cemetery in terms of the iron assemblages and techniques. Also, without a small nexus like Taicheng, the transportation of finished products and scrap iron would have become a daunting challenge to an ancient state.

Second, these small iron foundries might have taken charge of the production of knives and tools of simple types through casting and hammering of bloom. The metallurgical analyses show that even the same type of goods would be produced by a different range of techniques and approaches. These production centers might have been responsible for recycling scrap iron pieces to make new products. But in terms of the recycling methods, products from certain centers also demonstrate certain technical variations. Even though workers from the same workshops might have used different traditions or techniques, this possibility, if it were the case, would only demonstrate the idea that these workshops were not entirely "standardized" in terms of every single procedure.

In these three cemeteries, objects that were made of recycled scrap iron were identified from two. In combination with the evidence from the Taicheng foundry, scrap iron was one major source of raw materials for these iron foundries. For this reason, the iron foundries could be self-sustained and generate a more homogenous allocation patterns in archaeological records. Furthermore, because of the limitation in transportation technology, the widespread of this type of iron foundry could supplement the iron market network and produced goods that might not be sufficiently supported by the exchange network. If workers were dueling with scrap iron, thus, they had to use anything (both raw materials and techniques) to maximize the production of tools.

Third, this pattern also indicates the existence of a "market system" that helped members in different parts of the basin to gain access to the assemblage of iron products. One defining features of the iron assemblage in the Han period is that the percentage of tombs in an area containing these items did not show a dramatic discrepancy between the capital and other local centers in the Guanzhong Basin. The market system during the Warring States period, however, was still in its preliminary stage, and indicated capital-dominated pattern; the percentages of commoner tombs in the capital area containing bronze and iron objects seem to be higher than those in other areas. This pattern indicates that the market system could not efficiently and effectively transport goods from the capital to distant regions. Eventually, residents in the center far away from the capital did not have the same access to metal objects as capital residents during the Warring States and Qin periods in the Guanzhong Basin in general.

In contrast, the assemblages of iron as well as bronze objects in Western Han cemeteries did not indicate a capital-dominated pattern across the landscape of the capital. Also, some cemeteries far away from the capital even presented a higher percentage of certain items that nearby the Chang'an capital. Since the percentages of all these items in the cemeteries associated with the capital were not particularly high, a large amount of iron tools and iron products might have been transported through a more developed market network, or a full "incorporated market system". To put it in a simple way: residents could access certain products if they had money during the Han period regardless of the distance to the exchange or production center. As a result, this system created a network that integrated different local regions together through the consumption of iron and bronze objects. Consequently, this new economic system generated a dramatic change and transformation in the allocation pattern between the Western Han and Warring States period.

Given the rapid increase regarding the demand of iron items and recycling of scrap iron objects, the appearance and distribution of small iron foundries such as Taicheng might be viewed as an indicator of the market system as well as an approach to address the new social demands. As I emphasized above, small foundries such as Taicheng were supposed to serve as small and local production centers; their targeted customers were primarily residents. Therefore, residents in different parts of the capital basin clearly had more access to a wide range of iron and bronze goods. Archaeologically, the transition to the Han dynasty represents a de-integration of the "dendritic" market network of iron and bronze objects and a change of the capital's functions. Only this degree of integration and connection by a market network fully captured the essentials of the "commodity economy" we discussed in Chapter 2.

Of course, the inter-site comparison of iron assemblages in burial contexts should not lead to an overestimation of the commodity exchange at the local level. Agricultural tools—which are almost absent in this statistical study—were unlikely to be distributed to centers through the commodity exchange. But this type of items was demanded more substantially than any other iron items in the assemblage. In the Han society, the provision and support of iron materials was involved a mixed economic structure. Market networks did play a key role in the moving of finished products, semi-finished items, and raw materials, but the network had to cooperate with the system of local production focusing on consumers in the same county. The commodity economy, in fact, consisted of networks operating at different regional levels. For the larger scale network, it primarily took charge of the transportation of raw materials in the form of iron ingots as well as final products that were not consumed on a large scale or did not require more professional skills. Meanwhile, the large-scale network also relied on the local foundries or nexuses in a network system to transform raw materials to supply items that were required on a massive scale and reduce the cost of transportation.

CHAPTER 9

CONCLUSION

The analyses of remains from the Taicheng iron foundry and iron objects from the Guanzhong Basin address various aspects of the iron industry in the Han period. Here I synthesize all analyses that were conducted in the previous chapters to illustrate the relationship between the iron industry and the Han economic system. I combine these lines of evidence to bring into focus two issues in particular. The first one is relevant to the local production system from a micro-prospective, namely the organization of the Taicheng foundry and its economic interaction with residents in the Taicheng site-complex. The second issue pursues the macro-prospective of the industry in the entire Guanzhong Basin. Based on the results discussed in Chapter 8, I will reconstruct and present the market network that connected the capital and other county-level settlements together. In the end, I will synthesize how the market network connected the Guanzhong Basin to other parts of imperial territory on an inter-regional level and address the economic role of iron commodities in the Han period.

9.1 The Production, Distribution, and Consumption of Iron Artifacts in the Great Chang'an Area during the Western Han Dynasty

9.1.1 Organization of production in the local production site

According to survey and excavation, the Taicheng foundry clearly was a small-size iron production site. But this type of foundry was neither a small family-run household workshop nor a state-control production center. Although the type of iron production sites such as Taicheng has been identified in previous archaeological works, the multi-methodological approaches present and add several new understandings about the operation of an iron foundry that have not been discussed before in significant detail (Figure 9.1).

First of all, this study clarifies the nature and production scale of the iron foundry. The Taicheng foundry solidly dates to the Early Western Han period, predating the implementation of the monopoly policy (117 BCE). During this time frame, the Han government was not interested in directly intervening in the iron industry, so in all likelihood, the foundry was a privately-owned business and run by an entrepreneur. Given the small scale of the excavation area and limited numbers of laborers, this iron foundry was specialized in the production of limited types of agricultural implements and daily-use tools. The reconstructed minimum number of completed molds (Chapter 5) of hoes and plows suggests the production scale—which is reflected by the total number of final products manufactured in a given period—might not be remarkably high. The assemblage of small iron foundries stands in stark contrast with other large-scale iron foundries that have been discovered in other locations, such as Wafangzhuang (Li 1995), in which the assemblage of final products includes a much wider range of items such as weights and measures, chariot-fittings, and vessels.

Since excavations selected the areas or spots with the highest density of remains identified through survey and augering, the remains excavated should be relatively representative of the original waste assemblages generated during the entire manufacture and operation of Taicheng. Even if each set of molds would have been reused ten times, the total number of products produced within the nighty-year operation is still very small—about 3,000~4,000 hoes, and about 1,000 plows—in relation to the entire population in the county (about 30,000~40,000, see discussion in Chapter 3). The products manufactured by this foundry, therefore, should be just sufficient for the residents in the Tai county; this almost eliminates the possibility that there would be surplus for residents in other counties. Within the limited area of the Tai county, workers or owners of the iron foundry could even sell final products directly to customers.

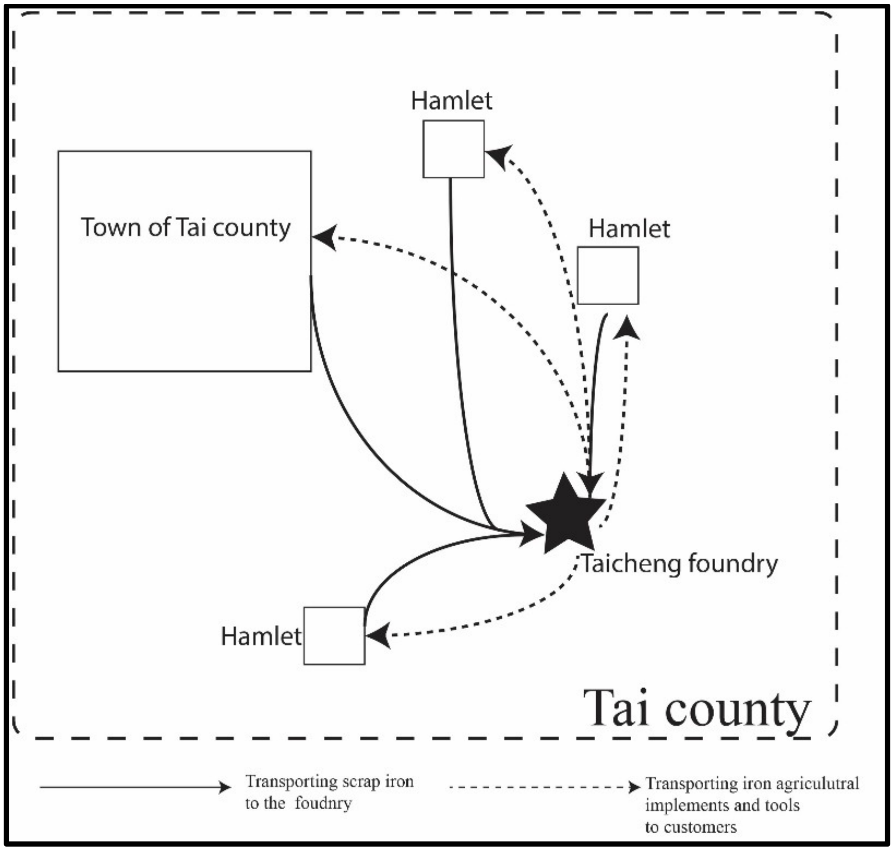

Figure 9.1 Reconstructed map showing the local production system
(Dotted-line represents a hypothetical boundary of Tai county in the Western Han period. The town of Tai county should be somewhere nearby the foundry, but it has not been confirmed yet in archaeological fieldwork. Besides the county town, the Tai county should consist of a number of hamlets or village-level small settlements, which may or may not be corresponding to the discovery of Qin-Han remains identified in survey)

Second, this iron foundry should include at least four sections or workstations in order to finish the entire manufacture process: mold making, casting, pig iron refining, and hammering. Although no kilns or ceramic manufacturing facilities have been found, the discovery of certain special types of remains, such as models and over-fired waste, indicates that mold production was conducted somewhere on the site. In other words, the Taicheng foundry should be able to conduct and finish all steps involved in cast iron production on its own. Yet, the evidence related to mold production was sporadically discovered in the excavated area, indicating the location of this section was away and separated from the casting section.

Furthermore, the metallurgical analysis of iron remains from the site indicates that recycled scrap iron might have been the major source for manufacture. These remains would have included corroded iron agricultural implements, knives, and cauldron vessels that were collected from nearby village settlements. A great portion of raw materials might come directly from the local settlement. At the same time, the operation of the foundry, I believe, was also linked to a transportation network in order to procure resources that were not locally available or accessible. Remains that would be used as “iron billets”, such as decarburized steel bars, were found from garbage pits, a piece of evidence showing the iron foundry might have imported certain numbers of raw materials or semi-finished materials to maintain daily production (Chapter 5 & 8). In other words, the local production system must have co-existed with a market-exchange system that allowed residents accessing to goods that a local foundry could not produce (Chapter 8).

Third, in terms of the forms of organization, the foundry was operated like a “factory” instead of a house-hold family-run workshop. The study of faunal remains shows that iron workers procured meat produced by other specialized meat producers (Chapter 6); these workers did not spend time raising their livestock or even preparing food. The study of the assemblage of ceramic vessels also indicates that drinking or serving vessels were rarely present. These iron workers might not even dwell on the site the entire day. Instead, workers came to the site solely for iron production, probably as hired laborers, and left when they finished their shift. The spatial distribution of remains further substantiates this viewpoint by showing a certain degree of “labor-division” between the four major production procedures, an indicator of “assembly-line” or “prescribed” organization.

Last but not least, the study of the standardization of technique, as well as the spatial distribution of remains, evidently falsifies the assumption I raised in the beginning that the organization of these iron workers did not present an idealized "streamlined" structure. Mold making, for instance, should involve multiple groups or teams of workers at the same time, given the variability in techniques (metric measurements and assembling markers) identified. Moreover, mold makers were allowed not only to make products in slightly different versions following their own practices but also to send their products to a specific group of casters. Eventually, each group of casting workers used the assemblages of molds consisting of different categories and representing different technical characteristics. All these scenarios are evidently illustrated by the distribution pattern in dumping pits identified in Chapter 7. To translate this pattern into social organization, I argue that workers at different stations or procedures should have communicated with each other and have some forms of collaboration, which leaves no doubt that workers were not entirely alienated from either their tools or final products.

The reconstructed local production system (Figure 9.1) had another significant implication. As I alluded to in Chapter 4, other iron foundries in the basin were also very small and produced similar assemblages of final products. I suggest the organizations of iron foundries at other county-level settlements in the Guanzhong Basin were similar to the case of Taicheng. The natures mentioned above might embody several essential aspects characterizing other iron foundries distributed throughout the entire Guanzhong Basin. Most importantly, these small iron foundries might have focused on agricultural implements and tried to supply local villagers with a number of items that could be manufactured in a small foundry setting by recycling scrap iron. Through this strategy, the local production might significantly reduce the cost and time associated with the transportation of agricultural tools over a long distance in order to maintain the provision of goods sufficient for each individual in the county.

9.1.2 Regional and interregional transportation

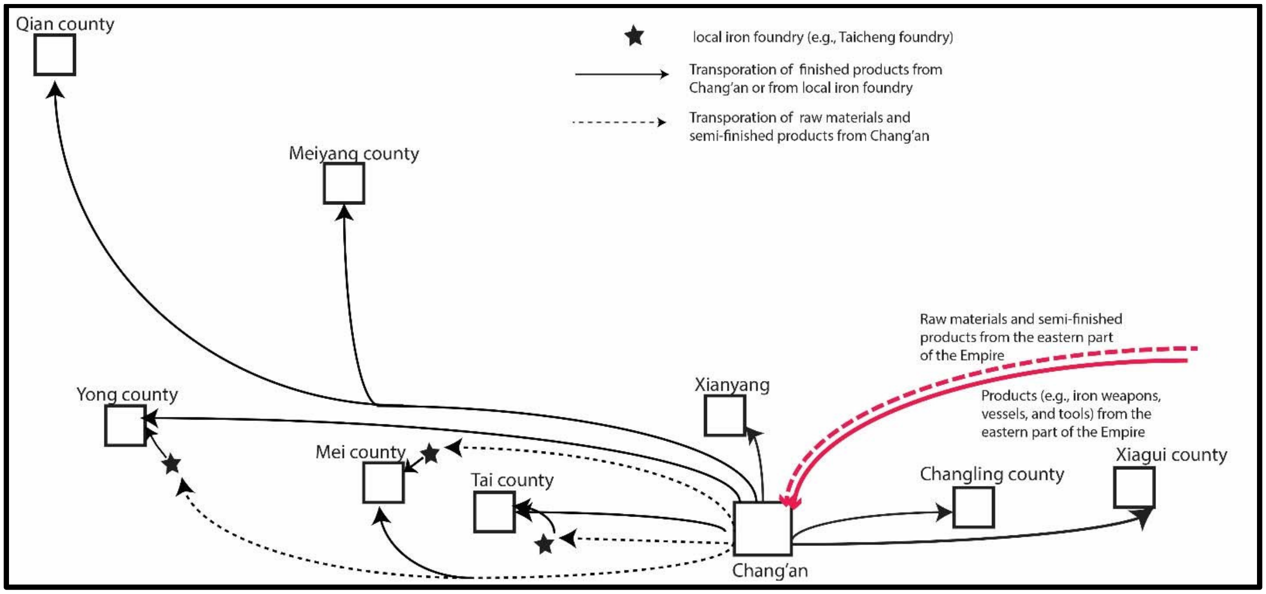

Figure 9.2 Reconstructed map showing the hypothetical regional market network
(Solid lines represent the transportation network of raw materials and semi-finished products. Dotted lines represent the transportation network of final products. Red lines represent the network through which iron materials were imported to Guanzhong)

The comparison between the Taicheng cemetery and foundry as well as the allocation pattern of iron objects from burials in the entire Guanzhong Basin demonstrates that the market economy and interregional transportation (Figure 9.2) played roles as essential agents in the distribution and procurement of iron commodities in the region. On the local scale, the operation of the Taicheng foundry and daily-life at the Taicheng site during the Han period had to heavily rely on this exchange network. The major type of raw materials for manufacturing iron knives—decarburized steel bars or billets—were most likely imported from other production centers outside the Guanzhong Basin. In addition, the assemblage of iron objects in the Taicheng cemetery indicates that a good number of daily-use items (e.g., vessels and spades) as well as weaponry must have been obtained through a market network from production centers outside Tai county.

On the regional scale, research on the allocation pattern of iron objects in burial contexts presents an ambiguous pattern regardless of the distance of any given area to the Chang'an capital. As I pointed out in Chapter 4, the Wei River and Cao canal were the major channels through which the Empire transported resources (e.g., staple goods) from its eastern territory. Even though some objects would have been manufactured in other regions (e.g., the Chengdu Plain), the high density of Han iron foundries and production sites in the East, especially in present-day Henan and Shandong provinces, unmistakably indicates that the eastern territory was one of the most important iron production areas. If this suggestion holds true, Chang'an should be the hub of transportation, from which iron resources were redistributed or radiated to other county-level settlements (e.g., Tai). Since the Han period is well-known for the development of commercial activities and market exchange (Chapter 3), this suggestion seems to be the most reasonable explanation for understanding the patterns of archaeological materials discoveries in the Guanzhong Basin.

Through the analysis of all burial data currently available, the allocation patterns demonstrate that the percentage of tombs burying iron items in any given area does not show any correlation with distance to the capital. According to Hirth's and other anthropologists' assumptions about the market, this pattern shows that market exchange—i.e., the movement of goods that was primarily determined by the demand of goods—was the main mechanism responsible for the allocation pattern I discovered. Consequently, residents, regardless of where they dwelled, could get access to the same assemblage of iron objects. It is also noteworthy that this regional transportation system rose alongside the formation of a unified Han Empire but still remained in its preliminary form during the Warring States period. Given the limited resources in the region, this regional network should be related to an interregional network that organized large-scale movement and transportation of staple goods from its eastern territory to support the dominance of Guanzhong over other parts of the Empire. Given the evidence of allocation, I propose that the movement of iron should be part of this transportation system coordinated and controlled by the Han government. In this regard, the market exchange of iron objects within the Guanzhong Basin recapitulates my suggestion about the "indirect intervene" of the Han government in the iron industry.

Intriguingly, the issue of the iron commodity economy in the Guanzhong Basin consists of elements which might seem contradictory. First, the distribution and procurement of a wide range of iron objects were primarily driven by market exchange and private entrepreneurial businesses, but all economic activities surrounding iron were not separated from state control and management. Even the iron monopoly after 117 BCE should be viewed as an intensification of state involvement in the iron industry instead of a fundamental transformation or revolution of its nature. Second, the assemblage of all iron objects that were accessible to residents should be attributed to both local production and market exchange. Results of metallurgical analysis of objects from the three cemeteries demonstrate that the subtle heterogeneity in manufacture techniques of the same types of objects. If iron workers in each local production center were allowed to manufacture objects following their own practices, this scenario fully explains the slight differences that I discovered in Chapter 8. More importantly, because of the difficulty of transporting large numbers of iron objects, the market system must cooperate with small, specialized iron foundries such as Taicheng. Since this type of foundries distributed quite ubiquitously throughout the entire Guanzhong Basin, the local production eventually made the commodity economy of iron possible and iron objects accessible by the majority of the population.

9.2 The Applicability of "Commodity" in the Study of the Han Economy

Having clarified and characterized the iron commodity economy in the Guanzhong Basin, I want to close the discussion about Taicheng by returning to James Carrier's framework that I discussed in Chapter 2. Below I list the comparison about various aspects (Table 9.1) to identify the extent to which the Han commodity economy of iron that was reconstructed in the dissertation is different from the framework proposed in Carrier's work about the capitalist commodity economy in 17th century Europe. The evaluation of this framework can eventually provide a workable base for addressing how an anthropological approach improves our understanding of the Han iron industry and economic system.

Table 9.1 Comparison between Carrier's framework and the commodity economy of iron in the Han period

	Capitalist commodity economy in the late 17th century	*The case study of Taicheng and the iron industry in Guanzhong during the Han period*
Location	Moving to a central place; separation of industrial areas from residential ones	Centralized center; workers intensively specialized in production at the site
Tools	Workers are less likely to own their own tools	Workers might emphasize personal markers on tools (molds)
Identity	Workers were treated as impersonal laborers	Workers emphasized their customs; the characteristics were recognized by other workers as well
Organizaiton	Increased division of labor; breaking-down of production into more and simpler steps; each step was routinized	Workers in each procedure would communicate with other groups
Exchange	Marketplace exchange took over; buying transaction became impersonalized	Local market and regional market exchange

In the case study, Taicheng was structured like a centralized "factory-like" foundry which employed full-time specialists to manufacture limited types of iron objects but operated on a small scale. In terms of the aspect of "location," Taicheng apparently matches the criteria of a commodities-producing factory in modern Europe. But the other aspects present key differences between the two cases. At the foundry, workers were allowed to produce casting molds or even final products following their own practices and habits. Casting workers also consciously made markers on molds (Chapter 7) to label or differentiate the molds that they would use or reuse. In terms of the organization, each group or team of mold-making workers selectively collaborated with specific groups of casting workers and sent products to them. Mold-making workers did not indiscriminately pass down the products to workers in the next workstation. In the last section, distribution, the final products manufactured by Taicheng might not be exchanged through the market system. Since the final products were sold only within the area of Tai county, the transaction might not be completely impersonalized. Although the local foundry manufactured seemingly “standardized” iron agricultural implements, its operation and the social relationship between producers and customers that was created through craft production were inherently different from a capitalist commodity workshop.

In terms of iron products such as daggers and cauldrons that were distributed through the regional market network, their nature is not as easy to evaluate as those manufactured by the local foundry. The obvious reason is that the provenances of these items are unclear. Even if they were manufactured by large iron foundries in the eastern territory (e.g., Wafangzhuang) that have been excavated in previous decades, the production organization of these foundries is still an issue that remains underexplored in literature. If my interpretation of the allocation pattern by using the framework “market exchange” holds true, however, these categories of iron products are more relevant to the concept “commodities” than products from the local foundry that I discuss here.

In general, iron products in the Han period were manfuactuerd for exchange, but they include differnet categories of "commodities" that involved different types of exchange networks and created various types of social connections. On the local scale, small county-level foundries specialized in agricultural implement production but targeted customers in the neighborhood. Products were exchanged within the area of a county, and the degree of commodification (or alienability) was relatively low. On the regional level, products were exchanged over a longer distance to different counties. Since these categoreis of iron products were more alienable, the market sysetm of these products took shape in a network that linked Chang'an captial and other county-level settlements outside the captial. Within this system, the extraction of resources from the region of rich resources must have involved the coordination of production in different geographical regions of the Empire. This connection generated not only momentum for the captial to achieve its domiannce over other territory but also a link that integrated different regions into an imperial economic system.

Besides military forces, previous scholarship has already emphasized the importance of state-sponsored rituals and ceremonies in solidifying the imperial rulership. By advocating and maintaining frequent sacrificial rituals, the Han emperors were able to gain control of sacred sites and thus, the spiritual domain which might have been translated into physical control (Puett 2002:313). In addition, as many scholars (e.g., Jiang 2003) already pointed out, the Guanzhong area was developed as much as a political as it was a ritual or ceremonial heartland, through constructing and maintaining numerous "detached palaces" and ritual temples in the Basin (Chapter 4). In the Han period, Chang'an was not only a capital but also a ritual center that embodied the model for other urban centers to replicate (Lewis 2006:308). Based on the research on iron commodities, I argue that the mechanism of iron production and distribution in

Guanzhong and interregional transportation also provided another important means to achieve imperial control. This aspect of rulership has been underappreciated and poorly understood in previous scholarship on the Han iron industry.

Through the network of iron commodities, the capital area developed a system that utilized and transformed iron resources into other materials that supported state military control (staple goods), which eventually fed back into the capital dominance. To maintain the system, the government must have intervened in the operation of the iron industry in order to effectively extract resources to the core even before implementing the monopoly to guarantee transportation to the center. Meanwhile, the center or core heavily relied on external resources, either in the form of final products, semi-finished products, or raw materials, imported from other parts of the Han Empire. The entire capital area was a consumption zone instead of a key craft production center of iron. The consumption of iron on a massive scale in the capital area might have made other territories become attached to the imperial control system and, consequentially, lose their original economic independence. Given this significance, the iron commodity economy was not a phenomenon driven by supply and demand; it might present a new form of political-economic relationship that was unprecedented in the predecessors of the Han Empire.

Just like other empires, the networks of the Han Empires, either in terms of politics or economy, were often fragmentary and fragile, and did not homogenously cover every part of its territory empire (Ballantyne and Burton 2012); the study of the iron industry exactly illustrates this aspect in the economic foundation of the Han Empire. Even in the capital area, the large-scale production network still did not seamlessly cover every type of iron product. The regional network, I believe, must have relied on small iron foundries like Taicheng to help the manufacture of iron products and provision of goods at the local level and cover the “holes” or "cavities" in the network. Through recycling scrap iron to manufacture limited types, but hugely demanded, agricultural implements, the foundry could not only facilitate and supplement the circulation of goods but also established a self-sustaining system.

9.3 Future Perspectives

In the end, I want to emphasize that the issue of the commodity economy only discloses the tip of the entire financial system. My future projects will continue to explore several issues as follows in order to make a more holistic view of the Han economy through archaeological study.

First, if the formation of the network depended on the political domain of Chang'an to draw and extract resources from the Guandong area, an interesting following-up question to investigate is, to what extent was the commodity economy in the Guanzhong Basin impacted by the political change and the relocation of the capital to Luoyang during the later Eastern Han period. To be specific, I will investigate whether the allocation pattern of iron objects in Eastern Han burials different from that in the Western Han period?

Second, this study laid the ground work for understanding of the regional difference in the organization of ironworks. For instance, to what extent did the production and organization of iron foundry in the eastern territory resemble the anthropological model of commodities? Did these workshops represent a higher degree of streamlined division in the labor organization?

Third, the iron network must be fueled by the provision and transportation of surplus, but how were iron products consumed and distributed in order to create enough surplus that could be extracted and transported to the capital? Were the assemblages of iron goods in the peripheries particularly deprived in order to preserve the resources to support the capital?

Lastly, the implementation of the iron monopoly did not indicate the end of the "commodity economy" in the Han period, but to what extent did the policies transform the patterns of production organization and product distribution in archaeological materials in the longue durée? In addition, what were the archaeological indicators for evaluating the intensification of state control in the iron industry?

In short, this study primarily contributes to the new understanding of the iron industry in the capital core by presenting new lines of evidence. Grounded in the framework of the "commodity", this study also demonstrates that the archaeological study of iron technology can depict not only the technical aspects of the iron industry but also its role in the imperial economic network. By developing new projects to address these issues mentioned above, the study of iron holds great promise for shedding new light on the economic system of the Han Empire.

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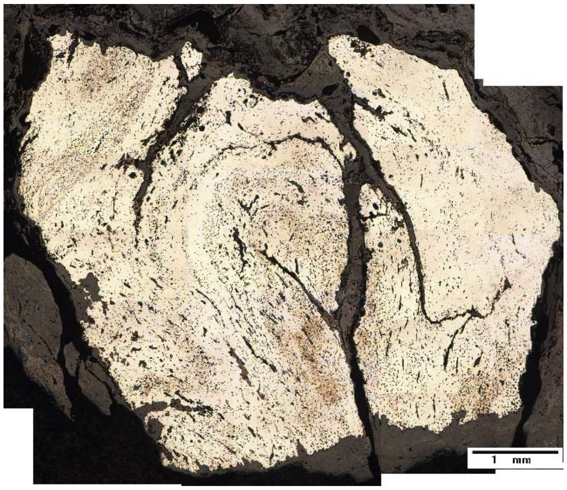
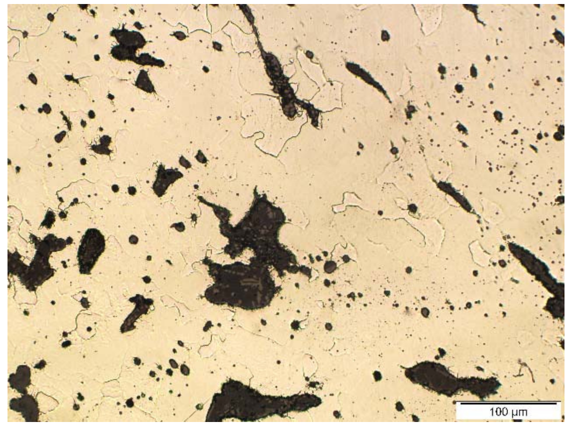
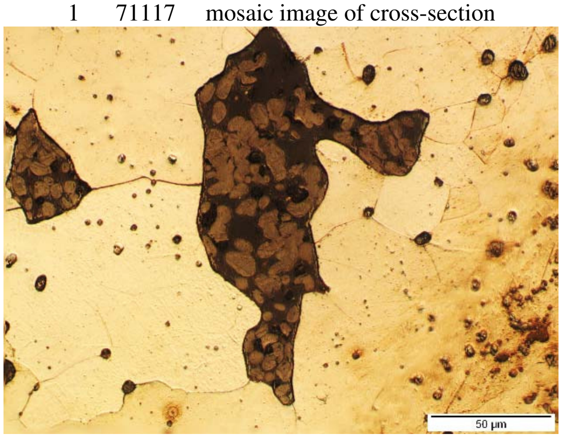
Appendix A – Photomicrographs of selected iron samples for metallurgical analysis



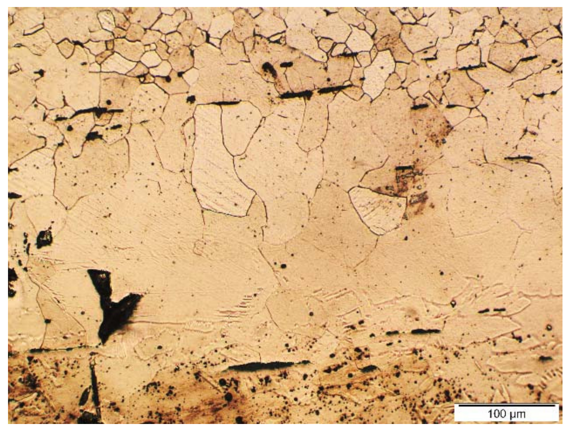
1 71117 mosaic image of cross-section



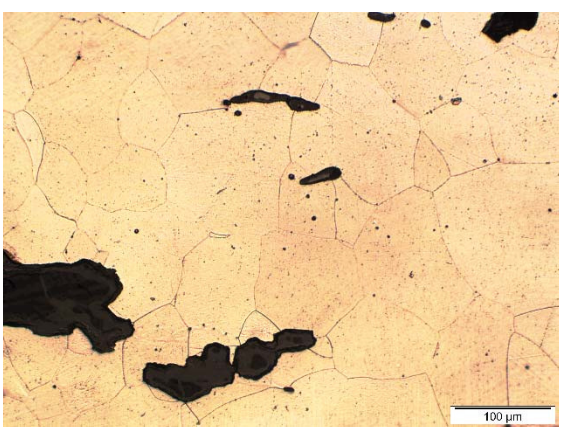
2 71117
Ferrite and elongated SI



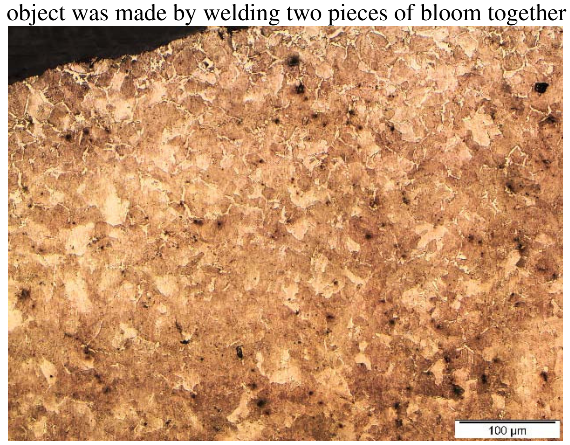
3 71121
Ferrite and SI with iron oxides



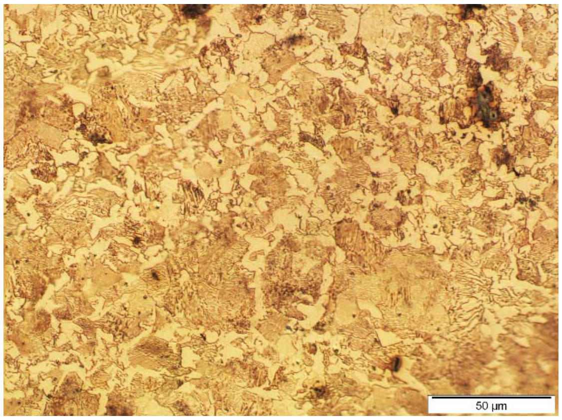
4 71126
Ferrite and SI. Elongated SI distributed along two horizontal lines. The size of grain in the center is larger, indicating the object was made by welding two pieces of bloom together



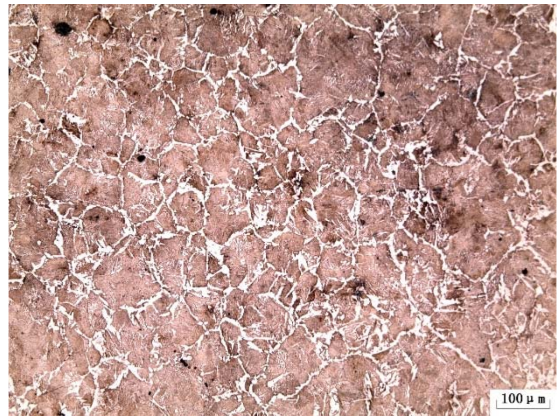
5 71119
Ferrite and SI



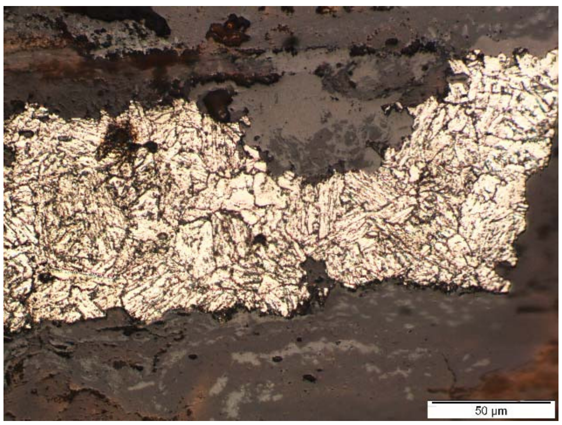
6 71170
Core: pearlite. Edge: pearlite and cementite



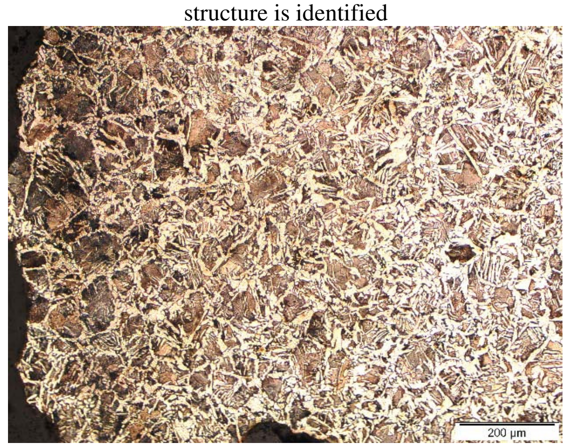
7 71174
Pearlite ferrite (hypoeutectoid steel)



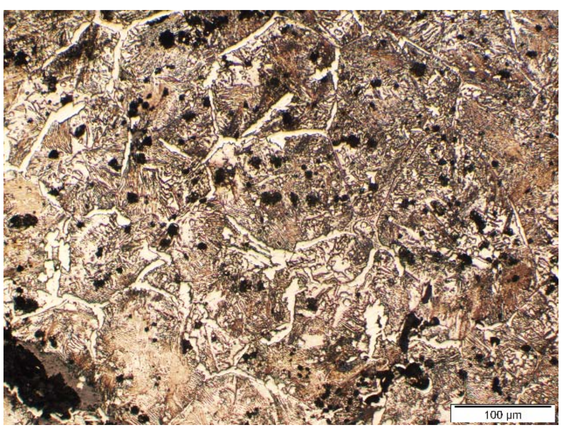
8 71290
Pearlite and cementite (hypereutectoid steel) widmanstatten structure is identified



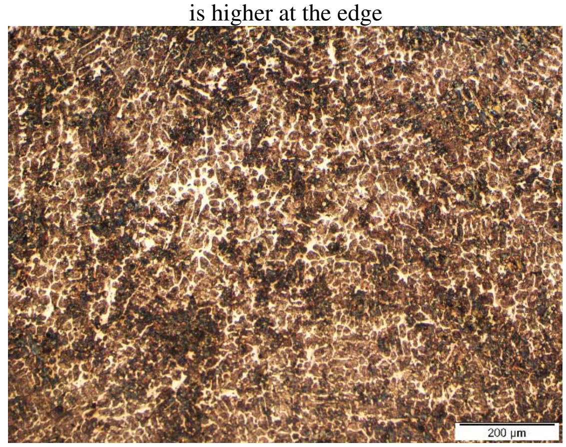
9 71186
Ferrite



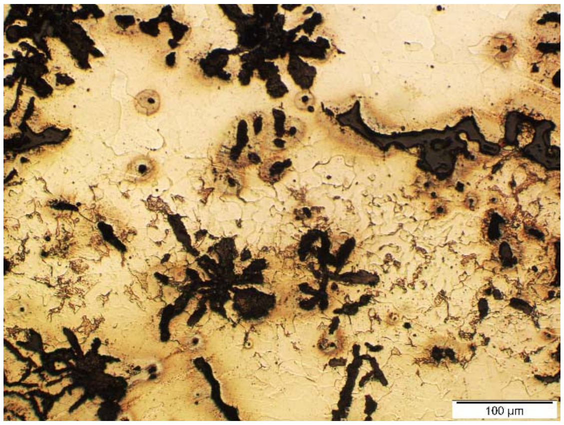
10 71108
Pearlitic ferrite and widmanstatten structure. Carbon conten is higher at the edge



11 71144:1
Pearlite and small amount of ferrite



12 71283
Pearlite and dendritic structure of ferrite. Hypoeutectic cast iron?

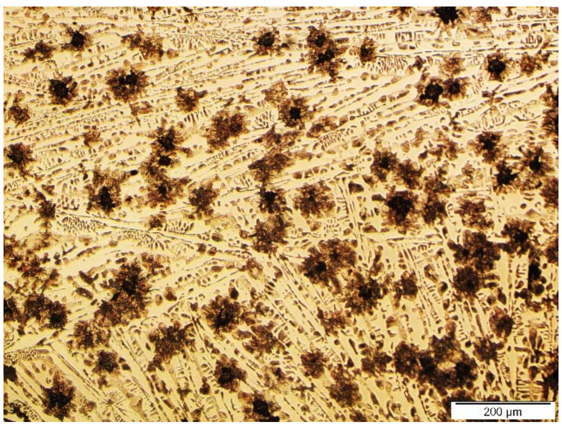


13 71153:3

Ferrite with graphite flakes. Center is a eutectic bended structure with small amount of pearlite

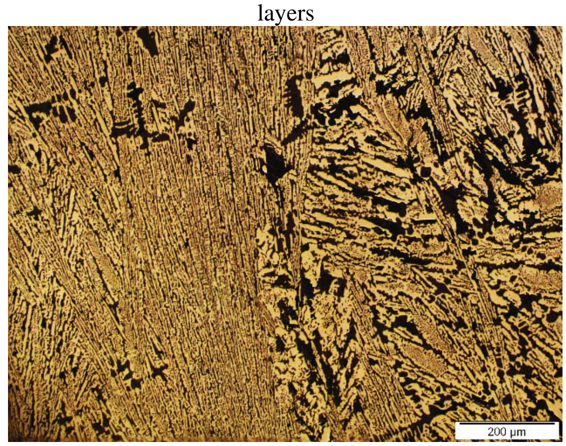
14 71274

Center is hypereutectic cast iron. Left side is ferrite and spherical graphite. There is a transition between these two layers



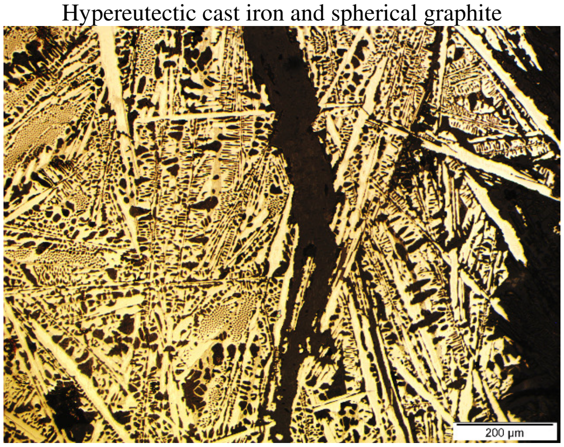
15 71120

Hypereutectic cast iron and spherical graphite



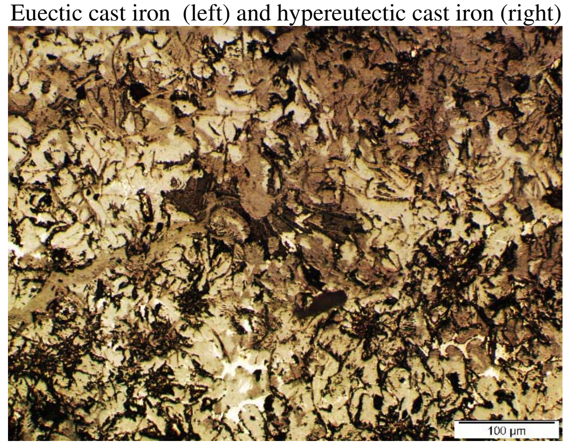
16 71232

Euectic cast iron (left) and hypereutectic cast iron (right)



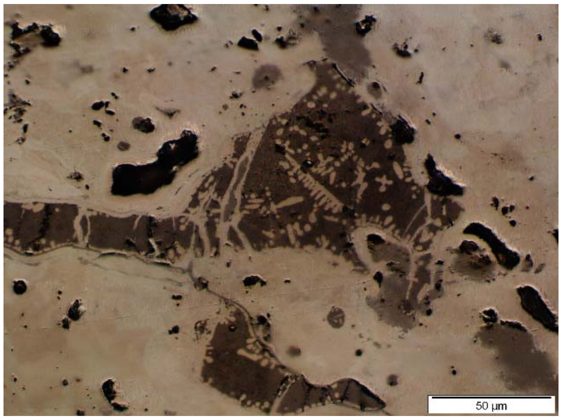
17 71264

Hypereutectic cast iron



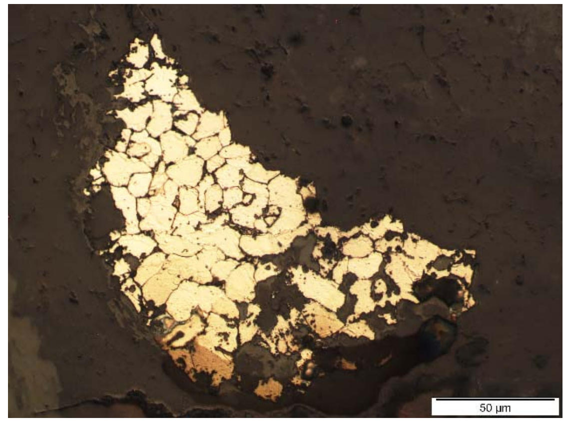
18 71106

Mottled cast iron. The structure shows graphite flakes and remains of pearlite



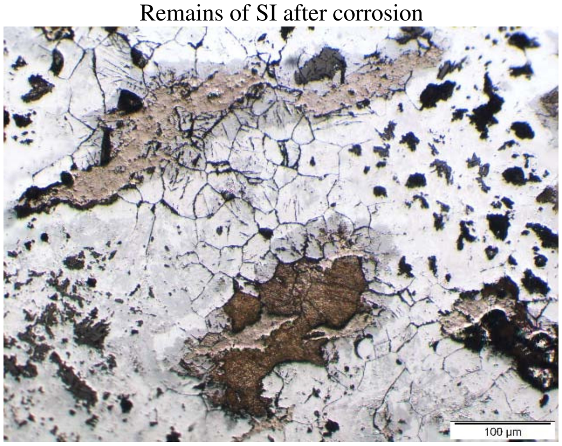
19 71148

Remains of SI after corrosion



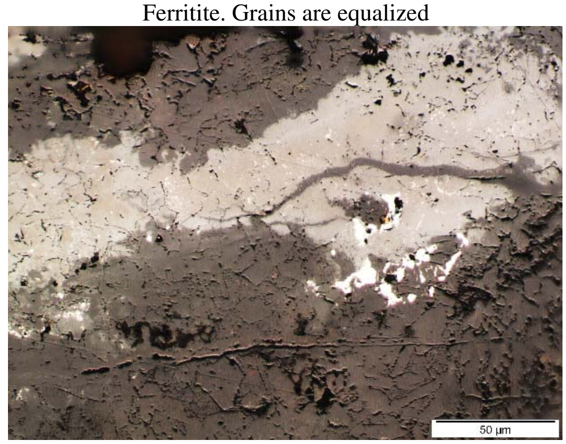
20 71171

Ferritite. Grains are equalized



21 71165

Remains of ferrite after corrosion



22 71150:1

Remains of ferrite and small amount of pearlite after corrosion

Appendix B- SEM-EDS Results of Slag and Iron Pieces from the Taicheng Foundry*

Table B.1 SEM-EDS Results of Glassy Slag

Lab no	sample no	note	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71149:1	H31②Y370		1.2	3.1	11.1	61.8	2.9		5.3	13.7	0.4	0.1	0.6
71149:1	H31②Y370		1.2	3.2	10.8	62.1	3.2		4.9	12.5	0.4	0.3	1.7
71149:1	H31②Y370		1.3	1.5	11.8	65.2	2.9		7.4	8.2	0.4		1.4
71149:1	H31②Y370		1.4	2.0	13.3	59.7	3.5		5.7	11.6	0.8	0.4	1.7
71149:1	H31②Y370		0.9	3.2	10.0	58.1	2.9		3.6	19.5	0.3	0.2	1.3
71154:2	H31①Y352	with lime	0.9	3.4	10.1	52.4	4.1	0.1	2.8	21.1	0.5	0.3	4.3
71154:2	H31①Y352		0.9	3.3	10.3	54.2	3.2		2.2	22.3	0.0		3.7
71154:2	H31①Y352		0.8	2.9	10.4	55.8	3.0		2.9	23.3	0.1		0.8
71154:2	H31①Y352		0.8	3.1	10.6	57.3	3.5		3.0	21.0	0.2		0.6
71155:2	H31②Y371		0.8	2.7	9.0	50.8	2.2		2.3	32.2			0.0
71155:2	H31②Y371		0.8	2.8	8.9	50.4	2.4		2.3	32.2			0.1
71155:2	H31②Y371		0.8	2.8	8.9	51.9	1.9		2.2	31.6			
71175:3	H33Y114		1.0	2.5	10.3	56.7	3.9		4.2	19.8	0.3	0.2	1.1
71175:3	H33Y114		0.9	2.4	9.3	55.6	3.6	0.1	4.2	21.7	0.8	0.5	0.7
71175:3	H33Y114		1.0	2.5	9.8	55.9	3.7		4.3	20.0	0.7	0.5	1.3
71175:3	H33Y114		1.0	2.5	9.9	55.1	3.7	0.1	4.2	20.1	0.7	0.5	1.8
71184	H33Y117		1.0	2.3	10.2	57.1	1.0		3.0	23.1	0.1		2.2
71184	H33Y117		1.1	2.3	11.0	59.2	0.6		3.6	21.2	0.3	0.1	0.7
71184	H33Y117		1.0	2.5	10.4	58.7	0.8		3.4	21.7	0.1		1.4
71184	H33Y117		1.1	2.3	10.5	56.1	1.4		3.0	20.2	0.1		5.4
71199:2	H9Y9		1.0	2.8	9.9	58.1	2.0		3.7	22.0	0.2		0.4
71199:2	H9Y9		0.9	2.8	9.8	57.1	2.1		3.5	21.7			2.1
71199:2	H9Y9		1.1	2.7	10.0	59.1	2.0		4.9	19.0	0.3	0.1	1.0

Table B.1 (Continued)													
71206:1	H36Y184		0.9	2.8	9.2	49.3	4.5		3.0	24.6		0.1	5.6
71206:1	H36Y184		1.0	2.8	10.0	52.6	3.0		3.5	20.7	0.2	0.2	5.9
71206:1	H36Y184		0.8	2.7	8.7	50.1	3.8		2.8	26.5		0.1	4.7
71206:1	H36Y184		0.8	2.7	8.8	51.3	2.8		3.4	28.0	0.6	0.4	1.0
71207	H36Y182		0.6	3.1	8.6	50.5	0.3		2.2	34.2			0.5
71207	H36Y182		0.7	3.2	8.7	50.2	0.9		2.4	33.4			0.5
71207	H36Y182		1.1	2.7	15.3	54.9	1.7	0.4	4.5	17.5	0.7	0.3	1.0
71207	H36Y182		0.7	3.1	8.8	50.3	1.1		2.6	33.0			0.5
71207	H36Y182	with high Al crystalline structure	1.1	4.4	14.1	55.2	1.6	0.4	4.9	15.1	1.1	0.6	0.8
71208:1	H36Y185		0.4	3.0	8.8	43.4	2.7	0.3	1.6	38.5	0.6	0.4	0.2
71208:1	H36Y185		0.4	2.6	11.0	43.3	3.0	0.5	2.3	35.5	0.9	0.4	0.2
71208:1	H36Y185		0.3	2.6	9.3	44.5	2.7	0.3	1.8	36.4	0.8	0.4	0.4
71208:1	H36Y185		0.4	3.3	11.9	43.0	2.4	0.3	2.2	34.9	0.8	0.5	0.2
71214:1	H28Y72		1.1	2.8	11.4	58.0	0.7		3.2	18.9	0.4	0.3	3.4
71214:1	H28Y72		1.1	2.8	10.7	57.8	0.9		3.2	19.6	0.6	0.4	2.8
71214:1	H28Y72		1.1	2.7	11.4	57.2	1.1		3.3	17.1	0.4	0.2	5.5
71214:1	H28Y72		1.1	2.9	11.4	57.7	0.9		3.0	18.4	0.3	0.1	4.2
71256	H39Y514		0.8	3.6	9.3	52.5	1.3		3.3	27.4	0.4	0.3	1.1
71256	H39Y514		0.7	3.7	9.2	52.3	1.0		3.2	28.4	0.2	0.3	1.0
71256	H39Y514		0.8	4.3	11.8	54.4	1.2	0.2	4.2	20.7	0.8	0.4	1.0
71256	H39Y514		0.8	3.7	9.0	51.4	1.0	0.1	3.4	28.0	0.6	0.5	1.0
71285	H31Y500		0.6	4.5	12.1	51.5	2.3		3.4	22.4	0.6	0.8	1.9
71285	H31Y500		0.6	3.6	9.6	50.7	1.7		2.6	29.4	0.1	0.3	1.6
71285	H31Y500		0.5	3.6	9.6	50.1	1.5		2.5	30.6	0.3	0.3	1.2
71285	H31Y500		0.5	3.0	12.1	58.9	1.5	0.4	2.3	18.7	0.8	0.5	0.8
71286	H31Y500		0.6	3.6	9.1	49.8	0.7		2.2	33.0	0.3	0.3	0.6

Table B.1 (Continued)

71286	H3①Y500		0.6	3.8	9.6	50.7	0.7		2.5	31.1	0.1	0.2	0.8
71286	H3①Y500		0.9	6.2	13.2	49.0	1.0	0.3	3.8	22.9	0.8	0.6	1.2
71286	H3①Y500	high Mg crystallian structure	0.4	17.3	4.5	71.2	2.6	0.1	0.8	0.9	0.4	0.1	1.1
71286	H3①Y500		0.5	8.7	11.8	57.1	1.7	0.2	3.2	13.8	0.8	0.6	1.5
71286	H3①Y500		0.7	7.1	11.7	56.2	1.5	0.3	3.6	15.1	0.9	0.6	1.6
71286	H3①Y500		0.6	5.3	10.3	50.7	0.8		2.4	27.7	0.3	0.3	1.5
71286	H3①Y500		0.6	4.8	9.3	51.1	1.1		2.3	28.5	0.3	0.4	1.6
71286	H3①Y500		0.8	4.4	11.9	58.1	1.9	0.3	4.0	14.5	0.9	0.6	2.2
71286	H3①Y500		0.8	6.1	13.7	50.2	1.5		3.9	20.3	0.8	0.6	2.1
71286	H3①Y500	lime	1.2	3.6	1.9	1.9	4.4	1.9	0.9	77.8	0.6	0.9	1.0
71286	H3①Y500		0.5	3.6	9.3	50.5	0.7		2.4	31.6	0.2	0.2	1.0
71236	H16Y93		0.9	2.4	10.6	56.4	1.1		2.6	23.8	0.3	0.1	1.7
71236	H16Y93		0.9	2.5	10.6	55.7	2.1		2.7	24.0	0.2	0.1	1.3
71236	H16Y93		0.9	2.6	10.1	53.9	2.4		2.9	24.1	0.7	0.4	1.7
71236	H16Y93		0.9	2.6	10.7	56.5	1.1		2.6	23.3	0.2	0.1	2.0
71257	H3⑧Y580		1.0	2.0	11.8	63.9	1.4		4.3	11.5	0.6	0.1	3.5
71257	H3⑧Y580		1.0	1.9	11.8	64.8	1.5		4.7	10.0	0.5	0.1	3.9
71257	H3⑧Y580		0.9	2.5	11.7	62.0	1.6		3.3	13.2	0.4	0.2	4.3
71257	H3⑧Y580		0.8	2.4	11.4	61.7	1.8		3.1	13.5	0.4	0.1	4.8
71205	H36Y183		0.9	2.7	10.0	53.7	2.7		3.2	25.3	0.2	0.1	1.1
71205	H36Y183			0.1	0.2	51.2	2.0			46.6			
71205	H36Y183		1.3	3.7	13.4	55.1	2.9		4.3	17.7	0.5	0.2	0.9
71205	H36Y183		1.4	2.1	14.3	55.5	3.1		5.1	17.1	0.4	0.4	0.7
71205	H36Y183		0.2	0.2	1.0	51.1	3.8		0.8	38.9		1.2	1.7
71205	H36Y183	lime	1.5	3.8	1.9	3.2	6.3	2.4	0.9	74.2	0.2	0.7	1.3
71205	H36Y183	high P crystallian structure	0.3	0.2	0.1	50.4	23.1	0.5	0.2	24.7	0.1	0.1	0.5

Table B.1 (Continued)

71205	H36Y183	lime	1.1	3.0	1.3	2.6	5.9	1.1	0.2	84.4		0.1	0.4
71205	H36Y183		0.2	19.1	0.0	72.9	6.1			1.0		0.2	0.5
71205	H36Y183	high Si crystallian structure	0.1	0.2	2.0	85.2	7.8		0.5	1.6	0.3	0.0	2.4
71205	H36Y183		1.1	3.2	10.1	55.1	3.0		3.0	23.4	0.2	0.2	0.8
71205	H36Y183	high Mg crystallian structure	0.3	22.4		71.3	4.7		0.1	0.5	0.1	0.1	0.6
71205	H36Y183		1.0	2.6	9.6	53.0	2.9		3.3	25.1	0.5	0.4	1.1
71182:1	H33Y115		0.9	2.4	9.4	56.6	2.3		3.3	24.6	0.1		0.5
71182:1	H33Y115		0.0	0.0	0.0	50.2	2.0		0.0	47.7			0.1
71182:1	H33Y115		0.9	2.6	9.8	56.3	2.0		3.4	24.2	0.2	0.1	0.4
71182:1	H33Y115		0.0	0.2	1.0	70.5	2.6		0.1	1.8		0.1	23.8
71182:1	H33Y115		1.0	2.5	10.2	56.9	2.1		4.1	20.9	0.9	0.4	0.5
71182:1	H33Y115		0.9	2.2	9.3	57.1	2.4		3.3	24.3			0.5
71182:1	H33Y115		0.9	2.3	9.1	54.7	2.1		3.2	23.1	0.6	0.4	3.0
71175:2	H33Y114		0.9	2.5	8.6	52.8	1.4		2.4	30.8	0.1	0.1	0.4
71175:2	H33Y114		0.8	2.5	8.5	53.1	1.2		2.3	31.6			0.2
71175:2	H33Y114	high Si crystallian structure	0.1	0.4	1.4	93.0	2.2		0.1	2.6			0.2
71175:2	H33Y114		1.1	2.7	9.5	55.8	3.8		3.0	15.8	0.6	0.4	6.9
71175:2	H33Y114		1.0	2.9	10.2	53.7	1.6		2.9	26.8	0.3	0.3	0.5
71206:2	H36Y184		1.1	2.4	9.5	55.3	1.4		3.0	26.4			0.9
71206:2	H36Y184		1.1	2.4	9.0	54.6	1.5		2.8	27.8	0.1		0.9
71206:2	H36Y184		1.0	2.3	9.4	54.8	1.7		2.8	27.3	0.2	0.1	0.4
71206:2	H36Y184		1.0	2.0	8.9	57.5	1.8		3.2	25.2			0.5
71183:1	H33Y116		1.0	2.8	9.9	57.8	2.6		4.0	20.4	0.2	0.2	1.2
71183:1	H33Y116		1.0	2.7	10.0	58.2	2.7		4.3	19.1	0.2	0.3	1.4
71183:1	H33Y116	iron oxide inclusion	0.4	0.1	0.0	4.1	6.1	0.2	0.3	1.9	0.3	0.6	85.6

Table B.1 (Continued)

71183:2	H33Y116		0.9	2.6	8.9	53.0	3.2		2.8	24.9		0.1	3.7
71183:2	H33Y116		0.8	2.6	8.8	52.3	2.5		2.5	29.2	0.1	0.1	1.2
71183:2	H33Y116		0.7	2.5	8.8	52.4	2.4		3.1	28.3	0.6	0.3	0.8
71183:3	H33Y116		0.8	3.3	9.3	52.1	2.0		2.7	29.3		0.1	0.5
71183:3	H33Y116		0.7	3.3	9.3	52.9	2.1		3.0	28.4			0.5
71183:3	H33Y116					51.1	1.6			47.3			
71183:3	H33Y116		0.8	3.1	9.1	52.1	2.1	0.1	3.3	27.9	0.6	0.3	0.5
71154:1	H31①Y352		1.0	2.9	10.0	57.1	0.3	0.3	3.9	19.7	0.7	0.5	3.8
71154:1	H31①Y352		1.0	3.0	10.0	57.3	0.2	0.2	3.9	20.4	0.6	0.3	3.1
71154:1	H31①Y352		1.0	2.8	10.0	58.5	0.4	0.4	4.2	18.0	0.8	0.4	3.5

Table B.2 SEM-EDS Results of Iron Globules in Glassy Slag

Lab no	sample no	feature	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71149	H31②Y370	P-Fe eutectic	0.0	0.4	0.7	2.2	18.9	0.5	0.2	0.5	0.0	0.2	75.8
71149	H31②Y370	P-Fe eutectic	1.2	1.3	1.2	2.6	18.8	0.6	0.2	0.6	0.1	0.2	73.0
71154:2	H31①Y352	Ferrite	0.3	0.4	0.6	0.9	7.2	0.8	0.3	0.5	0.4	0.3	87.7
71154:2	H31①Y352	Ferrite	1.3	1.5	1.4	1.7	7.4	1.5	0.6	0.7	0.8	0.6	81.4
71154:2	H31①Y352	Pearlite	1.0	1.0	0.8	1.1	10.4	0.7	0.1	0.2	0.2	0.3	83.9
71154:2	H31①Y352	Pearlite	0.0	0.2	0.3	0.8	9.9	0.4	0.1	0.3	0.2	0.2	87.2
71154:2	H31①Y352	Ferrite	0.3	0.2	0.3	0.9	13.9	1.3	0.1	0.3	0.0	0.1	82.2
71154:2	H31①Y352	Ferrite	1.2	1.1	0.9	1.2	9.9	1.1	0.1	0.3	0.2	0.3	83.4
71154:2	H31①Y352	P-Fe eutectic	0.8	0.9	0.8	1.2	18.3	4.0	0.0	0.2	0.0	0.3	73.1
71154:2	H31①Y352	P-Fe eutectic	0.8	0.9	0.8	1.2	18.7	2.4	0.1	0.3	0.1	0.2	74.3
71154:2	H31①Y352	Pearlite	0.2	0.3	0.4	0.8	16.3	0.7	0.1	0.3	0.1	0.3	79.8
71154:2	H31①Y352	Pearlite	0.6	0.6	0.7	1.1	17.0	1.0	0.1	0.3	0.1	0.3	77.2
71154:2	H31①Y352	P-Fe eutectic	0.8	0.9	0.9	1.2	20.4	1.2	0.0	0.3	0.1	0.3	73.8
71154:2	H31①Y352	P-Fe eutectic	0.8	1.0	0.8	1.2	20.0	1.2	0.1	0.2	0.1	0.2	74.1
71182:1	H33Y115	P-Fe eutectic	0.7	0.8	0.7	1.1	18.6	0.6	0.1	0.4	0.2	0.3	75.9
71182:1	H33Y115	Whole area scanning	1.1	1.4	1.3	1.7	6.3	1.4	0.6	0.7	0.5	0.5	83.0
71182:1	H33Y115	Whole area scanning	1.0	1.1	1.0	1.5	14.8	1.0	0.2	0.3	0.1	0.2	78.7
71175:3	H33Y114	Ferrite	0.8	0.9	0.8	1.0	7.8	0.5	0.1	0.3	0.2	0.3	86.7
71175:3	H33Y114	Ferrite	0.1	0.3	0.4	1.0	7.2	0.8	0.3	0.5	0.3	0.4	87.7
71175:3	H33Y114	Ferrite	0.2	0.2	0.4	0.8	7.2	0.7	0.3	0.5	0.3	0.3	88.5
71175:3	H33Y114	Ferrite	0.9	0.9	0.9	1.2	7.8	0.5	0.1	0.3	0.2	0.3	86.6
71205	H36Y183	Whole area scanning	0.8	0.9	0.8	1.2	14.4	1.7	0.1	0.3	0.1	0.3	79.2
71206:1	H36Y184	Whole area scanning	1.0	1.1	1.0	1.8	14.6	0.9	0.2	0.3	0.2	0.3	77.9
71206:2	H36Y184	Ferrite	1.3	1.4	1.4	2.3	4.4	1.5	0.5	0.8	0.5	0.6	83.4
71206:2	H36Y184	Ferrite	1.3	1.4	1.3	2.5	4.5	1.5	0.6	0.7	0.4	0.6	83.1

Table B.2 (Continued)

71206:2	H36Y184	Pearlite	1.2	1.5	1.5	1.9	5.1	1.4	0.6	0.7	0.5	0.5	83.5
71206:2	H36Y184	Pearlite	1.3	1.5	1.4	1.8	5.0	1.5	0.6	0.8	0.4	0.6	83.4
71206:2	H36Y184	P-Fe eutectic	0.1	0.1		0.6	19.8	0.1	0.0	0.4	0.1	0.2	78.2
71206:2	H36Y184	P-Fe eutectic	0.0	0.1	0.1	0.7	19.6	0.2	0.1	0.4	0.1	0.2	77.9
71206:2	H36Y184	Pearlite	0.1	0.2	0.1	0.7	6.3	0.3	0.2	0.5	0.2	0.3	90.7
71206:2	H36Y184	Pearlite	0.2	0.0	0.0	0.6	6.2	0.2	0.1	0.4	0.1	0.3	91.5
71207	H36Y182	P-Fe eutectic	0.7	0.9	0.7	1.1	21.2	0.6	0.1	0.4	0.1	0.2	73.8
71207	H36Y182	P-Fe eutectic	0.5	0.7	0.6	1.1	20.7	0.6	0.1	0.4	0.1	0.2	74.5
71207	H36Y182	P-Fe eutectic	0.6	0.6	0.5	0.9	12.5	0.4	0.2	0.5	0.2	0.3	82.6
71207	H36Y182	P-Fe eutectic	0.2	0.4	0.5	1.0	19.7	0.9	0.4	0.7	0.3	0.4	74.6
71214	H28Y72	Ferrite?	0.1	0.4	0.8	2.4	19.6	1.2	0.1	0.6	0.1	0.3	74.2
71214	H28Y72	Ferrite?	1.0	1.1	1.5	3.9	18.7	1.7	0.2	0.7	0.1	0.2	70.8
71214	H28Y72	P-Fe eutectic	0.1	0.2	0.4	2.1	21.2	1.0	0.2	0.4	0.0	0.2	74.0
71214	H28Y72	P-Fe eutectic	0.0	0.2	0.4	2.3	20.5	0.8	0.1	0.5	0.1	0.2	74.6
71214	H28Y72	Pearlite	0.1	0.1	0.0	0.3	7.5	0.2	0.2	0.4	0.2	0.3	90.5
71214	H28Y72	Pearlite	0.0	0.1	0.0	0.4	6.2	0.2	0.1	0.4	0.1	0.1	92.2
71214	H28Y72	Pearlite+ferrite	0.2	0.4	0.5	1.1	5.2	0.8	0.3	0.6	0.3	0.5	89.0
71214	H28Y72	Pearlite+ferrite	1.2	1.5	1.3	1.8	5.4	1.5	0.5	0.8	0.3	0.6	83.0
71214	H28Y72	Whole area scanning	0.1	0.3	0.4	0.9	5.9	0.7	0.3	0.5	0.3	0.4	89.2
71285	H3①:Y500	P-Fe eutectic	0.6	0.7	0.7	1.0	19.8	0.6	0.1	0.2	0.0	0.2	75.6
71285	H3①:Y500	P-Fe eutectic	0.1	0.3	0.3	0.8	20.1	0.5	0.0	0.2	0.0	0.2	77.1
71285	H3①:Y500	Pearlite	1.0	1.0	0.9	1.2	6.3	0.7	0.1	0.2	0.0	0.3	87.9
71285	H3①:Y500	Pearlite	0.9	0.7	0.6	1.0	11.4	0.4	0.0	0.1	0.0	0.2	84.4
71285	H3①:Y500	Whole area scanning	1.0	1.2	1.2	1.7	17.2	1.5	0.5	0.6	0.4	0.4	72.8
71184	H33Y117	Whole area scanning	0.1	0.1	0.2	0.3	5.2	0.7	0.1	0.2	0.1	0.2	92.5
71199:2	H9Y9	Pearlite	1.3	1.5	1.4	1.9	8.7	1.5	0.6	0.8	0.4	0.5	79.5

Table B.2 (Continued)

71199:2	H9Y9	P-Fe eutectic	0.8	0.9	0.9	1.3	20.9	0.6	0.1	0.2	0.1	0.2	73.4
71236	H16Y93	P-Fe eutectic	0.7	0.7	0.7	1.1	20.1	0.9	0.1	0.2	0.2	0.2	74.7
71257	H3⑧Y580	Ferrite	1.1	1.4	1.3	7.3	2.7	1.4	0.6	0.6	0.5	0.6	81.1
71257	H3⑧Y580	P-Fe eutectic	1.1	1.3	1.2	3.6	13.6	1.3	0.5	0.6	0.4	0.6	74.2
71257	H3⑧Y580	Pearlite	1.1	1.3	1.3	7.2	2.8	1.4	0.6	0.7	0.5	0.6	80.8
71257	H3⑧Y580	P-Fe eutectic	1.0	1.3	1.2	1.6	13.6	1.5	0.6	0.8	0.4	0.5	75.8
71257	H3⑧Y580	Pearlite	1.1	1.6	4.3	16.8	8.0	0.6	1.1	3.2	0.4	0.4	62.0
71257	H3⑧Y580	Pearlite	1.1	1.4	1.2	1.6	6.2	1.4	0.5	0.6	0.3	0.4	83.4
71257	H3⑧Y580	P-Fe eutectic	0.6	0.7	0.6	1.0	13.2	0.9	0.1	0.1	0.1	0.3	81.9

Table B.3 SEM-EDS Results of Fe-rich Slag Samples

Lab no	sample no	feature	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71291	H1Y21	Matrix+crystallization	0.1	3.1	8.3	39.8	3.7	1.3	0.7	40.4	1.3	0.7	0.5
71291	H1Y21	Matrix+iron prill	0.3	1.8	5.1	36.5	6.9		0.5	33.5	0.4	0.4	13.9
71291	H1Y21	Matrix+crystallization	0.1	2.3	8.9	40.0	3.7	1.5	1.0	40.0	1.5	0.7	0.3
71291	H1Y21	Matrix+iron prill	0.0	5.7	6.7	44.6	9.6	0.2	0.2	22.4	1.4	0.5	8.3
71139	H31①Y331	Matrix	1.1	0.9	14.1	63.5	3.5	0.3	6.3	7.2	0.9	0.3	1.7
71139	H31①Y331	Matrix	1.3	1.1	14.7	59.5	3.5	0.6	6.2	8.9	1.1	0.2	2.4
71139	H31①Y331	Glassy matrix	1.1	2.1	11.0	57.6	3.2	0.3	4.3	12.6	0.8	0.2	6.8
71139	H31①Y331	Glassy matrix (with quartz)	0.9	2.7	9.5	56.0	2.3		4.3	23.4	0.2	0.1	0.5
71139	H31①Y331	Glassy matrix	1.4	0.7	16.7	57.9	3.6	0.7	7.8	6.8	1.2	0.6	1.8
71139	H31①Y331	Glassy matrix(wustite)	0.8	1.9	8.2	33.9	3.4	0.1	1.3	4.6	0.5	0.3	44.2
71147:2	H31①Y347	Wustite	0.3	0.4	2.6	15.8	2.1		0.6	1.7	0.3	0.3	75.8
71147:2	H31①Y347	Wustite+fayalite	0.7	0.6	4.4	37.5	2.2		1.3	2.5	0.2	0.2	50.3
71147:2	H31①Y347	Matrix(with quartz)	0.8	0.8	9.2	76.7	1.4		4.1	1.1	0.6		5.3
71147:2	H31①Y347	Matrix with wustite	1.3	0.9	7.9	49.5	1.7		2.3	2.7	0.3	0.2	33.0
71147:2	H31①Y347	Fayalite	0.9	1.0	5.1	39.8	2.3		1.4	4.0	0.4	0.3	44.7
71147:2	H31①Y347	Fayalite	0.7	0.8	4.6	32.8	2.9		1.2	3.6	0.2	0.2	53.1

Table B.4 SEM-EDS Results of Furnace Lining Samples

Lab no	sample no	feature	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71152:8	H31①Y344：1-22	With un-molten Ti minerals	1.25	1.51	11.29	67.34	3.52		3.66	2.06	3.50	0.00	5.87
71152:8	H31①Y344：1-22	Whole area scanning	1.31	1.45	12.32	69.61	3.37		3.73	2.35	0.67	0.08	5.09
71152:8	H31①Y344：1-22	Whole area scanning	1.30	1.48	11.78	67.49	2.93		3.39	4.78	1.10	0.27	5.08
71152:8	H31①Y344：1-22	Whole area scanning	1.02	1.74	11.65	64.13	2.59		2.36	10.41	0.48	0.12	5.43
71162:1	H31①Y329:1-4	With un-molten Ti minerals	1.24	1.36	11.71	70.43	2.15		3.35	1.75	2.72	0.00	5.29
71162:1	H31①Y329:1-4	Whole area scanning	1.67	1.23	13.80	65.02	2.16		3.17	7.90	0.74	0.09	4.04
71162:1	H31①Y329:1-4	Whole area scanning	1.10	1.30	11.72	71.37	3.70		3.81	1.30	0.55	0.15	4.92
71211:2	H36①Y190:1-2	Whole area scanning	1.34	0.76	12.05	71.67	1.71		8.02	2.33	0.28	0.08	1.67
71211:2	H36①Y190:1-2	With un-molten quartz	0.04		0.44	96.19	1.92	0.19	0.05	0.06	0.11	0.31	0.45
71211:2	H36①Y190:1-2	With un-molten quartz	0.11	0.05	0.50	97.44	1.66						0.23
71211:2	H36①Y190:1-2	Whole area scanning	1.65	2.05	11.74	62.33	1.39		5.53	13.11	0.49	0.00	1.72
71211:2	H36①Y190:1-2	With un-molten quartz	0.06		0.44	96.11	1.95	0.34	0.14	0.00	0.00	0.19	0.36
71211:2	H36①Y190:1-2	Adjacent to quartz	1.89	1.61	13.79	63.54	2.07		6.81	6.50	0.70	0.23	2.59
71211:2	H36①Y190:1-2	Adjacent to quartz	1.31	0.53	11.01	74.21	1.26		8.14	2.18	0.17	0.06	1.14
71211:2	H36①Y190:1-2	Adjacent to quartz	1.79	1.56	14.14	63.68	2.30		6.90	4.95	0.62	0.14	3.85
71197	H9Y12	Whole area scanning	1.86	1.72	17.10	64.50	2.46		5.17	1.45	0.63	0.05	5.06
71197	H9Y12	High P mineral	0.04			37.85	57.65	1.01	0.18	0.31	0.20	0.45	0.88
71197	H9Y12	adjacent to quartz	2.12	1.62	17.38	64.61	1.72		5.03	1.99	0.44	0.17	4.92
71197	H9Y12	With un-molten quartz	1.26	0.89	10.23	77.03	2.32	0.14	3.84	1.04	0.34	0.05	2.88
71197	H9Y12	Whole area scanning	1.44	2.07	15.20	66.35	2.27		3.88	1.85	0.79	0.16	5.87
71197	H9Y12	With high Ni iron prill	0.81	0.84	0.81	1.19	4.87	0.48	0.16	0.21	0.20	0.29	89.63
71197	H9Y12	Whole area scanning	1.27	2.16	15.13	65.25	2.71		3.54	2.15	0.78	0.18	6.79
71197	H9Y12	Ti-Fe mineral	0.73	8.35	2.79	2.42	2.30	0.55	0.20	0.14	69.25	0.10	13.01

Table B.5 SEM-EDS Results of Iron Samples

Lab no	Slag inclusions	Point	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71117	SI1	P1	0.5	0.8	1.0	3.6	1.0	0.3	0.2	1.9	0.3	0.7	89.8
71117	SI1	P2	0.7	0.8	0.8	1.9	0.7	0.3	0.2	0.7	0.2	0.7	93.1
71117	SI1	P3	0.5	0.5	0.2	2.7	25.4	0.0	1.6	40.4	0.3	0.4	27.9
71117	SI1	P4	0.2	0.4	0.2	2.2	27.1	0.1	1.6	41.8	0.3	0.5	25.6
71117	SI1	P5	0.4	0.3	0.3	0.4	0.1	0.1	0.1	0.0	0.1	0.3	97.9
71117	SI1	P6	0.7	0.8	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.3	94.9
71117	SI1	P7	0.3	0.5	0.3	3.1	24.3	0.0	1.4	37.3	0.2	0.5	32.2
71117	SI1	P8	0.4	0.3	0.2	2.4	26.1	0.0	1.4	42.1	0.0	0.5	26.7
71117	SI1	P9	0.6	0.7	0.6	0.6	0.5	0.5	0.3	0.2	0.1	0.4	95.6
71117	SI1	P10	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.2	0.1	0.2	97.8
71117	SI2	P1	0.2	0.4	0.8	7.4	15.2	0.2	0.6	9.1	0.2	1.3	64.6
71117	SI2	P2	0.0	0.5	0.7	3.4	18.1	0.1	0.6	13.5	0.3	1.3	61.5
71117	SI2	P3	0.8	0.6	0.7	0.8	1.4	0.1	0.4	0.3	0.2	0.4	94.3
71117	SI2	P4	0.6	0.8	0.5	0.6	0.8	0.1	0.2	0.2	0.0	0.3	96.0
71117	SI2	P5	0.3	0.2	0.0	0.2	1.2	0.3	0.1	0.8	0.2	0.2	96.6
71117	SI2	P6	0.2	0.1	0.1	0.2	0.6	0.1	0.1	0.3	0.1	0.3	97.8
71117	SI2	P7	0.5	0.5	0.4	0.5	0.5	0.3	0.1	0.1	0.1	0.3	96.8
71117	SI2	P8	0.4	0.6	0.4	0.4	0.4	0.2	0.1	0.1	0.1	0.2	97.0
71117	SI2	P9	0.2	0.6	1.9	4.6	20.0	0.3	0.9	14.5	0.1	1.2	55.7
71117	SI2	P10	0.1	0.4	2.4	4.9	18.8	0.2	0.8	12.7	0.1	1.3	58.4
71117	SI3	P1	0.8	0.7	0.2	1.7	28.8	0.0	0.8	53.5	0.0	0.0	13.6
71117	SI3	P2	0.6	0.6	0.1	1.9	28.4	0.1	0.8	52.8	0.1	0.4	14.2
71117	SI3	P3	0.7	0.7	0.1	3.1	26.2	0.0	0.8	47.5	0.2	0.4	20.3
71117	SI3	P4	0.9	0.7	0.2	3.5	25.9	0.1	1.0	45.0	0.1	0.2	22.5
71117	SI3	P5	0.4	0.5	0.5	1.5	1.6	0.2	0.3	2.6	0.2	0.3	92.0
71117	SI3	P6	0.4	0.4	0.6	2.2	2.2	0.1	0.2	3.7	0.3	0.6	89.2
71117	SI3	P7	1.2	0.6	0.9	5.9	16.8	0.2	0.7	25.8	0.1	0.4	47.3

Table B.5 (Continued)

71117	SI3	P8	1.2	0.8	1.1	5.9	16.3	0.3	0.8	26.4	0.1	0.3	46.7
71117	SI3	P9	0.8	0.4	0.4	3.8	7.6	0.1	0.7	15.5	0.3	0.4	70.1
71117	SI3	P10	0.9	0.7	0.9	4.3	6.8	0.6	0.6	12.8	0.1	0.5	71.8
71117	SI3	P11	0.8	0.5	0.6	3.5	7.5	0.4	0.5	10.2	0.1	0.3	75.6
71117	SI3	P12	0.7	0.4	0.5	2.5	4.7	0.2	0.3	6.2	0.2	0.1	84.1
71117	SI3	P13	0.9	0.5	0.9	7.3	5.0	0.2	0.7	11.0	0.3	0.4	72.9
71117	SI3	P14	1.0	0.4	1.1	7.6	5.8	0.3	0.6	11.8	0.2	0.5	70.9
71117	SI3	P15	1.1	0.7	0.3	2.3	22.6	0.1	0.9	38.2	0.1	0.2	33.5
71117	SI3	P16	1.3	0.8	0.4	2.4	22.9	0.1	0.8	38.6	0.2	0.3	32.2
71117	SI3	P17	0.2	0.2	1.3	1.5	0.0	0.1	0.1	0.4	0.1	0.4	95.7
71117	SI3	P18	0.2	0.4	1.3	1.7	0.5	0.3	0.2	0.6	0.3	0.4	94.2
71117	SI4	P1	0.4	0.4	0.4	1.0	0.2	0.5	0.2	0.7	0.3	0.6	95.4
71117	SI4	P2	0.2	0.3	0.6	1.1	0.5	0.5	0.2	0.4	0.1	0.4	95.9
71117	SI4	P3	0.6	0.7	5.3	11.5	1.0	0.2	0.5	5.5	0.8	0.6	73.4
71117	SI4	P4	0.6	0.7	4.5	10.3	1.0	0.3	0.4	4.6	0.7	0.4	76.2
71117	SI4	P5	0.9	0.8	4.9	18.5	2.9	0.1	1.8	10.4	0.4	1.2	58.3
71117	SI4	P6	0.8	1.0	4.6	18.0	2.9	0.1	1.5	9.8	0.5	1.6	59.3
71117	SI4	P7	0.4	0.6	1.2	3.9	0.8	0.5	0.3	2.1	0.2	0.7	89.4
71117	SI4	P8	0.5	0.7	1.0	3.2	0.7	0.6	0.2	1.5	0.2	0.6	91.0
71117	SI5	P1	0.2	0.0	0.4	2.0	3.8	0.0	0.1	0.2	0.2	0.4	92.8
71117	SI5	P2	0.2	0.3	0.5	2.1	3.5	0.1	0.1	0.2	0.1	0.2	92.9
71117	SI5	P3	1.4	0.6	0.5	0.8	1.1	0.7	0.2	0.5	0.1	0.4	93.8
71117	SI5	P4	0.0	0.1	0.1	0.3	0.2	0.2	0.1	0.2	0.1	0.3	98.3
71117	SI5	P5	0.0	0.2	0.2	0.3	0.2	0.1	0.2	0.1	0.1	0.3	98.4
71117	SI5	P6	0.2	0.1	0.1	0.2	0.3	0.1	0.2	0.2	0.2	0.4	98.2
71117	SI5	P7	0.0	0.1	0.1	0.2	0.4	0.2	0.2	0.2	0.2	0.4	98.1
71117	SI5	P8	0.0	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.3	98.2
71117	SI6	P1	0.0	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.3	98.5
71117	SI6	P2	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	99.1

Table B.5 (Continued)

71117	SI6	P3	0.0	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.3	98.8
71117	SI6	P4	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	98.9
71117	SI6	P5	0.7	0.6	1.6	1.5	2.7	0.2	0.2	2.0	0.2	0.4	90.0
71117	SI6	P6	0.6	0.4	4.2	3.6	4.0	0.0	0.2	3.1	0.3	0.4	83.2
71117	SI6	P7	0.7	0.5	0.5	7.9	10.3	0.0	0.4	7.4	0.2	0.9	71.1
71117	SI6	P8	0.0	0.4	0.5	5.9	4.4	0.0	0.4	1.9	0.2	0.7	85.8
71117	SI6	P9	0.5	0.7	0.3	5.8	17.3	0.1	0.6	16.9	0.1	0.9	56.9
71117	SI6	P10	0.5	0.5	0.3	5.5	12.8	0.0	0.6	10.8	0.1	0.8	68.1
71119	SI1	p1	0.0	0.3	0.1	19.9	1.2	0.0	0.2	2.5	0.1	0.4	75.3
71119	SI1	p2	0.1	0.4	0.1	19.8	0.9	0.0	0.2	1.1	0.1	0.4	76.9
71119	SI1	p3	0.0	0.2	2.6	14.5	3.4	0.1	0.3	0.7	0.3	0.4	77.6
71119	SI1	p4	0.2	0.1	1.3	11.5	2.8	0.2	0.3	0.5	0.2	0.4	82.5
71119	SI1	p5	0.4	0.2	19.7	10.7	2.1	0.0	1.4	0.3	0.4	0.4	64.5
71119	SI1	p6	0.2	0.2	4.6	8.8	1.9	0.0	0.4	0.2	0.1	0.4	83.3
71119	SI1	p7	0.2	0.3	0.5	18.2	2.2	0.0	0.2	0.6	0.2	0.4	77.3
71119	SI1	p8	0.2	0.2	0.8	16.3	3.8	0.0	0.4	1.1	0.1	0.4	76.7
71119	SI2	p1	1.1	0.4	0.4	1.5	20.2	0.0	1.3	33.6	0.2	0.3	41.1
71119	SI2	p2	0.5	0.3	0.7	1.1	9.7	0.1	0.7	14.3	0.1	0.4	72.2
71119	SI2	p3	0.3	0.7	1.1	18.9	4.7	0.0	0.2	2.7	0.2	0.4	70.8
71119	SI2	p4	0.2	0.7	0.5	19.0	2.9	0.0	0.1	1.1	0.2	0.5	74.9
71119	SI3	p1	0.6	0.5	0.4	0.6	0.7	0.6	0.3	0.2	0.1	0.2	95.8
71119	SI3	p2	0.0	0.0	0.0	0.1	0.3	0.1	0.1	0.2	0.2	0.5	98.6
71119	SI3	p3	0.6	0.6	0.4	0.6	0.6	0.5	0.2	0.2	0.1	0.3	95.9
71119	SI3	p4	1.0	0.8	0.7	0.8	0.8	0.8	0.5	0.4	0.3	0.3	93.6
71119	SI3	p5	0.9	0.9	0.9	1.6	0.8	0.6	0.6	0.6	0.3	0.4	92.6
71119	SI3	p6	0.9	0.9	0.8	1.2	0.7	0.4	0.2	0.2	0.1	0.3	94.3
71119	SI4	p1	0.0	1.3	1.5	8.8	9.9	1.0	0.5	7.6	0.3	0.9	68.3
71119	SI4	p2	0.5	1.1	2.1	11.8	10.8	0.6	0.8	8.8	0.3	0.9	62.3
71119	SI4	p3	0.5	0.9	1.8	10.2	9.8	0.6	0.4	8.0	0.1	1.0	66.7

Table B.5 (Continued)

71119	SI4	p4	0.1	0.2	0.1	0.6	0.9	0.2	0.1	0.3	0.1	0.2	97.2
71119	SI4	p5	0.1	0.2	0.1	0.4	0.6	0.1	0.1	0.2	0.1	0.2	97.9
71119	SI5	p1	0.3	1.5	3.2	18.5	13.9	1.2	2.0	18.2	0.3	1.0	40.2
71119	SI5	p2	0.5	1.3	3.6	23.0	8.8	1.2	2.3	8.7	0.3	1.2	49.1
71119	SI5	p3	0.1	0.1	0.0	0.3	0.3	0.6	0.1	0.1	0.2	0.3	98.0
71119	SI5	p4	0.0	0.1	0.1	0.3	0.2	0.6	0.2	0.2	0.1	0.4	97.9
71119	SI5	p5	0.1	0.1	0.1	0.3	0.2	0.8	0.1	0.2	0.2	0.5	97.4
71119	SI5	p6	0.2	0.1	0.1	0.5	0.1	0.6	0.1	0.2	0.2	0.4	97.5
71119	SI5	p7	0.5	0.1	0.3	1.6	1.1	0.8	0.2	0.4	0.1	0.3	94.6
71119	SI5	p8	0.3	0.0	0.0	1.0	0.7	0.7	0.2	0.3	0.2	0.5	96.2
71119	SI5	p9	0.4	0.1	0.8	3.1	0.4	0.6	0.3	0.6	0.1	0.4	93.3
71119	SI5	p10	0.4	0.1	0.6	2.6	0.5	0.7	0.3	0.5	0.1	0.4	93.9
71119	SI5	p11	0.4	0.4	0.9	4.5	5.2	0.5	0.5	8.0	0.3	0.5	78.8
71119	SI5	p12	0.3	0.4	0.7	3.5	5.2	0.3	0.4	8.0	0.1	0.5	80.8
71121	SI1	p1	0.2	0.7	0.5	10.6	15.5	0.0	0.4	8.6	0.1	0.7	62.9
71121	SI1	p2	0.3	0.9	0.2	9.3	14.7	0.1	0.3	8.1	0.2	0.8	65.0
71121	SI1	p3	0.1	0.4	0.6	1.5	1.2	0.1	0.2	0.6	0.2	0.6	94.6
71121	SI1	p4	0.0	0.1	0.6	0.4	0.3	0.2	0.1	0.2	0.2	0.4	97.6
71121	SI1	p5	0.2	0.4	1.2	5.7	5.7	0.3	0.7	3.4	0.1	0.6	81.7
71121	SI1	p6	0.0	0.2	0.7	0.6	0.4	0.2	0.1	0.4	0.2	0.4	96.9
71121	SI1	p7	0.4	0.8	0.5	8.9	13.3	0.1	0.3	6.9	0.1	0.8	67.9
71121	SI1	p8	0.5	0.6	0.3	7.2	13.9	0.1	0.4	8.0	0.3	0.8	67.8
71121	SI1	p9	0.2	0.6	1.6	7.9	8.2	0.8	1.4	5.4	0.2	0.7	73.0
71121	SI1	p10	0.0	0.2	0.8	1.0	0.9	0.1	0.2	0.7	0.2	0.4	95.5
71121	SI2	p1	0.2	0.8	0.8	8.3	19.4	0.1	1.4	17.6	0.1	0.6	50.6
71121	SI2	p2	0.3	0.8	0.7	8.3	17.5	0.0	1.4	15.4	0.1	0.5	55.0
71121	SI2	p3	0.0	0.2	0.6	1.2	0.6	0.1	0.2	0.5	0.2	0.3	96.1
71121	SI2	p4	0.2	0.2	0.6	1.0	1.1	0.0	0.1	0.7	0.2	0.3	95.5
71121	SI2	p5	0.3	0.8	0.9	10.1	17.9	0.0	1.2	12.3	0.2	0.6	55.8

Table B.5 (Continued)

71121	SI2	p6	0.2	0.9	0.9	9.7	18.3	0.0	1.3	13.4	0.1	0.6	54.7
71121	SI2	p7	0.3	0.7	1.0	10.3	18.1	0.0	1.5	12.7	0.1	0.5	54.8
71121	SI2	p8	0.4	0.9	1.1	10.2	17.7	0.1	1.4	12.7	0.2	0.7	54.6
71121	SI2	p9	0.0	0.3	0.5	1.4	1.9	0.0	0.1	1.5	0.1	0.3	93.9
71121	SI2	p10	0.2	0.2	0.5	0.3	0.1	0.1	0.1	0.2	0.1	0.2	98.0
71121	SI3	p1	0.2	0.6	0.4	6.0	16.8	0.2	0.6	9.9	0.2	0.8	64.3
71121	SI3	p2	0.0	0.3	0.5	2.1	4.8	0.1	0.3	2.4	0.2	0.6	88.8
71121	SI3	p3	0.1	1.0	0.3	6.8	21.0	0.0	0.2	9.5	0.2	0.6	60.4
71121	SI3	p4	0.2	1.1	0.3	7.7	19.2	0.0	0.2	6.9	0.1	0.7	63.6
71121	SI3	p5	0.0	0.1	0.5	0.4	0.1	0.1	0.1	0.2	0.2	0.4	98.1
71121	SI3	p6	0.2	0.3	0.7	0.8	0.9	0.1	0.1	0.5	0.2	0.2	96.1
71121	SI3	p7	0.5	0.6	0.4	0.5	0.3	0.2	0.1	0.1	0.1	0.2	96.9
71121	SI3	p8	0.0	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	97.6
71121	SI4	p1	0.4	0.7	0.9	7.0	13.3	0.3	0.7	7.4	0.1	0.8	68.4
71121	SI4	p2	0.4	0.5	1.3	5.5	10.8	0.9	0.9	5.6	0.2	0.6	73.3
71121	SI4	p3	0.6	0.2	0.1	1.3	1.6	0.2	0.2	0.9	0.2	0.4	94.3
71121	SI4	p4	0.3	0.2	0.0	0.7	0.5	0.2	0.1	0.3	0.1	0.3	97.5
71121	SI4	p5	0.4	0.5	0.3	4.1	6.6	0.2	0.2	2.5	0.2	0.7	84.3
71121	SI4	p6	0.3	0.3	0.5	0.7	0.9	0.1	0.1	0.6	0.2	0.3	96.1
71121	SI4	p7	0.4	0.8	0.5	8.1	18.0	0.1	0.5	11.1	0.2	0.8	59.6
71121	SI4	p8	0.4	0.7	0.5	8.0	16.5	0.1	0.6	10.6	0.2	0.7	61.7
71121	SI4	p9	0.5	0.4	0.8	2.0	2.0	0.0	0.2	0.9	0.2	0.4	92.6
71121	SI4	p10	0.4	0.4	0.7	3.9	6.4	0.1	0.4	3.2	0.2	0.5	83.9
71126	SI1	p1	0.3	1.1	2.5	14.4	9.8	0.0	1.1	12.2	0.2	0.4	57.8
71126	SI1	p2	0.4	0.9	1.7	9.1	5.2	0.5	0.7	6.4	0.3	0.6	74.2
71126	SI1	p3	0.6	0.6	0.5	0.5	0.3	0.2	0.2	0.1	0.1	0.3	96.7
71126	SI1	p4	0.2	0.4	0.2	0.4	0.3	0.3	0.2	0.2	0.1	0.4	97.4
71126	SI1	p5	0.0	0.4	1.1	6.8	1.2	0.2	0.5	2.2	0.2	0.5	86.9
71126	SI1	p6	0.3	0.5	0.6	2.1	0.7	0.5	0.5	1.1	0.3	0.4	93.2

Table B.5 (Continued)

71126	SI2	p1	0.1	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.6	96.3
71126	SI2	p2	0.1	0.2	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.3	98.5
71126	SI2	p3	0.4	0.6	1.0	6.1	1.2	0.3	0.2	1.2	0.1	0.4	88.6
71126	SI2	p4	0.5	0.4	0.4	0.8	0.3	0.2	0.1	0.2	0.1	0.3	96.8
71126	SI2	p5	0.6	1.0	1.4	7.1	6.3	0.7	0.7	8.3	0.2	0.3	73.4
71126	SI2	p6	0.5	0.7	0.8	2.3	1.5	0.3	0.2	1.6	0.1	0.2	91.8
71126	SI3	p1	1.2	1.4	2.0	7.7	12.7	0.6	0.8	18.3	0.2	0.4	54.8
71126	SI3	p2	0.2	0.4	0.8	2.1	1.7	0.5	0.4	1.9	0.1	0.3	91.5
71126	SI3	p3	0.2	0.7	2.4	11.8	2.0	1.5	0.7	3.6	0.3	0.5	76.4
71126	SI3	p4	0.1	0.4	0.9	2.8	0.8	0.6	0.4	1.2	0.0	0.2	92.7
71126	SI3	p5	0.0	0.3	0.2	0.5	0.2	0.1	0.2	0.4	0.2	0.3	97.6
71126	SI3	p6	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.3	98.6
71126	SI3	p7	0.2	0.5	1.3	4.0	2.5	0.2	0.3	3.7	0.1	0.4	86.8
71126	SI3	p8	0.7	0.9	0.9	1.5	1.0	0.7	0.7	1.1	0.6	0.6	91.3
71126	SI4	p1	0.0	0.9	0.3	2.9	20.2	0.5	0.1	9.7	0.1	2.2	63.1
71126	SI4	p2	0.1	0.5	0.3	1.8	7.0	0.8	0.0	2.9	0.0	0.8	85.7
71126	SI4	p3	0.0	0.1	0.5	1.3	1.6	0.4	0.1	0.5	0.2	0.6	94.8
71126	SI4	p4	0.2	0.2	0.3	0.9	1.6	0.6	0.1	0.4	0.1	0.4	95.1
71126	SI4	p5	0.1	0.6	0.0	6.7	10.3	0.9	0.2	5.0	0.2	2.0	73.9
71126	SI4	p6	0.2	1.0	0.1	7.8	12.9	0.9	0.2	3.6	0.1	1.6	71.6
71126	SI5	p1	0.0	0.0	0.1	1.6	1.7	0.2	0.2	0.9	0.2	0.8	94.5
71126	SI5	p2	0.0	0.4	0.4	1.4	1.4	0.5	0.4	0.9	0.4	0.7	93.6
71126	SI5	p3	0.3	0.5	0.4	7.5	2.0	0.2	0.1	0.5	0.1	1.5	86.9
71126	SI5	p4	0.4	0.6	0.5	2.1	1.3	0.5	0.4	0.7	0.2	0.7	92.7
71126	SI5	p5	0.0	0.2	0.0	0.2	0.2	0.1	0.1	0.1	0.1	0.3	98.7
71126	SI5	p6	0.1	0.1	0.1	0.3	0.3	0.2	0.1	0.1	0.1	0.3	98.3
71126	SI5	p7	0.0	0.5	0.2	15.1	9.5	0.3	0.3	3.3	0.2	3.2	67.5
71126	SI5	p8	0.2	0.4	0.1	16.8	6.7	0.1	0.2	1.8	0.3	3.0	70.4
71126	SI6	p1	0.0	0.2	0.5	1.2	2.9	0.5	0.5	1.9	0.4	0.8	91.3

Table B.5 (Continued)

71126	SI6	p2	0.2	0.4	0.5	0.7	1.0	0.4	0.3	0.5	0.2	0.5	95.4
71126	SI6	p3	0.0	0.1	0.1	0.5	0.3	0.1	0.1	0.3	0.1	0.3	98.2
71126	SI6	p4	0.0	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	97.4
71126	SI6	p5	0.1	0.2	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.3	98.6
71126	SI6	p6	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3	98.7
71126	SI6	p7	0.0	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.3	98.7
71126	SI6	p8	0.0	0.1	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.3	98.8

Appendix C. Supplemental Tables of Faunal Remains Analyses

Table C.1 Body Part Representation of Horses and Sheep/Goat from Taicheng

	Horse	Sheep/goat
Skull		4
Mandible		7
Axial		
Cervical		
Thoracic		
Lumbar		
Sacrum		1
Scapula		5
Proximal humerus		1
Distal humerus	4	1
Proximal radius		
Shaft radius	1	2
Distal radius	1	
Proximal Ulna		1
Distal Ulna		
Carpal		
Pelvis		
Proximal femur		
Shaft femur		
Distal Femur		
Proximal tibia		
Shaft tibia	1	1
Distal tibia	1	1
Calcaneus		
Astragalus	2	
Metatarsus		
Metacarpus		
Metapodia		2
Phalanx	4	1

Table C.2 Counts of Butchery Marks Frequency by Body Parts from Taicheng

	Cattle	Dogs	Horses	Sheep/Goats	Pigs	Large mammals	Medimum mammals
Skull	c1				c1		
Mandible	s1	ch1,c1			ch1,s1		
Axial							
Atlas							
Cervical vertebra							
Thoracic vertebra						c1	
Lumbar vertebra							
Ribs	c1					ch1	
Sacrum							
Scapula							
Humerus	c1	c2	c1	ch1	c1	c1	
Radius	c4, sh1	c3	c1				
Ulna						c1	
Carpal	ch1						
Pelvis							
Femur	c1	c1				ch1,c1	c2
Tibia	c2						
Calcaneus	c 1						
Astragalus							
Tarsal							
Metatarsal	s1, sh2						
Metacarpus	sh4, s1, c1						
Metapodia	sh1						
1st phalange			c1				
2nd phalange							
3rd phalange							

C: cut marks; ch: chop marks; s: scrape marks; sh: shear marks

Table C.3. Counts of Teeth Eruption and Wear-degree of Pigs from Taicheng

pig	dp3	dp4	p2	p3	p4	m1	m2	m3
			erupting*1	a*3	erupting*1	b*1 (L)	socked*2 (U)	a*1 (U)
			socked*1		a*1	c*3 (L)	a*2 (L)	b*1 (U)
		d*1 (L)			b*3	d*1 (L) d*2 (U)	b*1 (U)	c*1 (L)
					d*1	h*1 (L)	c*1 (L)	
							f*1 (L)	

Table C.4 Body Part Representation of Identified Species from Zhonghang

NISP	Cattle	Pigs	Sheep/goat	Dogs	Deer	Large Mammals	Mammals	Bird	Horses	Mussel	Carnivora
Skull	42	77	7	12	4		7		3		
Mandible	61	98	12	14	8	1	1		9		
Vertebra	2					60	72				
Atlas	10	4	2	1	1		1		1		
Axis	7		1	3		2	1				
Cervical vertebra											
Thoracic vertebra											
Lumbar vertebra											
Sacrum		2		1	1	1					
Scapula	30	31	10	3	4	16	17		13		
Humerus	33	32	5	2	5	10	3		2		
Radius	16	12		7	8	2	5		3		
Ulna	23	15	6	5		1					
Carpal											
Pelvis	14	28	7	3	3	1	4		6		
Femur	18	27		7	8	10	12		3		
Tibia	31	30	5	7	12		13		4		
Calcaneus	23	7	1		9		1		3		
Astragalus	13	2			6		5		1		
Metatarsus	22	2	2	2	3				2		
Metacarpus	20	2	5	5	2		1		2		
Metapodia	16		1						1		
Phalanx	29	2			16				60		
Teeth	61	25		3			1		3		
Tarsal	10										
Ribs	8					155	90				
Fibula		2					1				
Shaft	43					65	83				
Horn	29		14								
Patella	1						1		1		

Table C.5 Counts of Epiphyseal Fusion of Cattle and Pigs from Zhonghang

	cattle					pig			
age of fusion	body part	u	e	f	age of fusion	body part	u	e	f
7-10 months	scapula			14	12 months	scapula			29
	acetabulum			7		proximal second phalanx			
12-18 months	distal humerus	1		22		distal humerus	4		15
	proximal radius			10		proximal radius			11
18 months	distal first phalanx			17		acetabulum	1		9
	distal second phalanx			7	24 months	distal metacarpal			
24-30 months	distal metacarpal	1		11		proximal first phalanx			
	distal tibia			12		distal tibia	5	1	12
27-36 months	distal metatarsal			14	24-30 months	calcaneum			
36-42 months	calcaneum	2	2	16	27 months	distal metatarsal			
42 months	proximal femur			2	30 months	distal fibula			
42-48 months	proximal humerus	1		6	36-42 months	ulna	9		9
	distal radius	1	3	8	42 months	proximal femur	4		1
	ulna	2		6		proximal humerus	1		2
	distal femur	1		10		distal radius	8	2	2
	proximal tibia	3	1	4		distal femur	10		3
						proximal fibula			
						proximal tibia	12		2

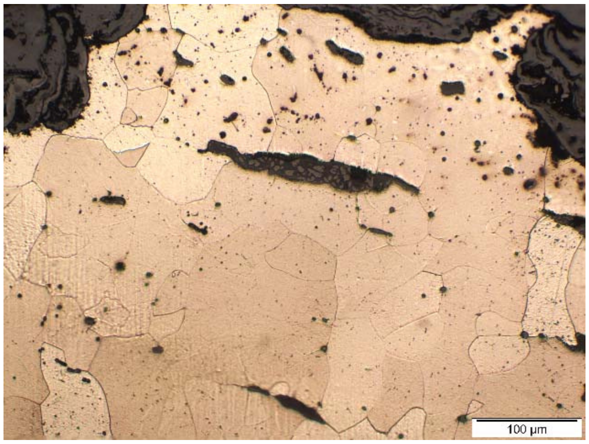
u : unfused; e : epiphyseal lines; f : fused

Table C.6 Counts of Epiphyseal Fusion of Caprine and Dogs from Zhonghang

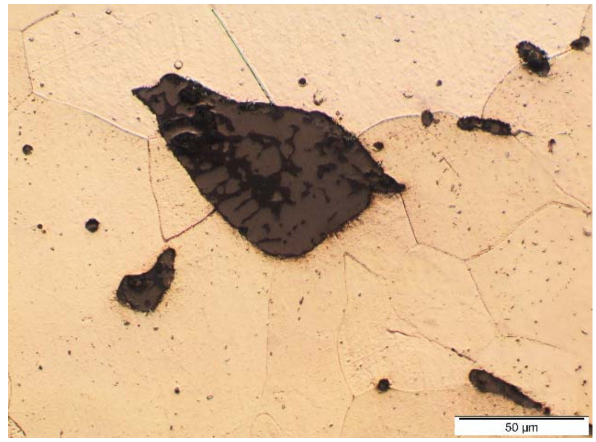
caprine					dog				
age of fusion	body part	u	e	f	age of fusion	body part	u	e	f
6-8 months	scapula				6 months	pelvis			
6-10 months	acetabulum				6-7 months	scapula			3
10 months	distal humerus			3	7 months	second pha prox			
	proximal radius			5	8 months	mc distal			2
13-16 months	distal first phalanx				8-9 months	distal humerus		1	
	distal second phalanx				9-10 months	ulna olecranon			7
18-24 months	distal metacarpal	2		3	10 months	distal metatarsal			
	distal tibia			2	11-12 months	ulna distal			7
20-28 months	distal metatarsal	1		1		radius prox			2
30 months	ulna					radius distal			3
30-36 months	calcaneum	1			13-16 months	tibia distal	1		3
	proximal femur					Calcaneus			
36 months	distal radius	3		1	15 months	humerus prox			1
36-42 months	proximal humerus	1		3		fibula distal			
	distal femur				15-18 months	fibula proximal			
	proximal tibia	1	1		1.5 years	femur prox	5		3
						femur distal	3		1
						tibia proximal	1		2

u : unfused; e : epiphyseal lines; f : fused

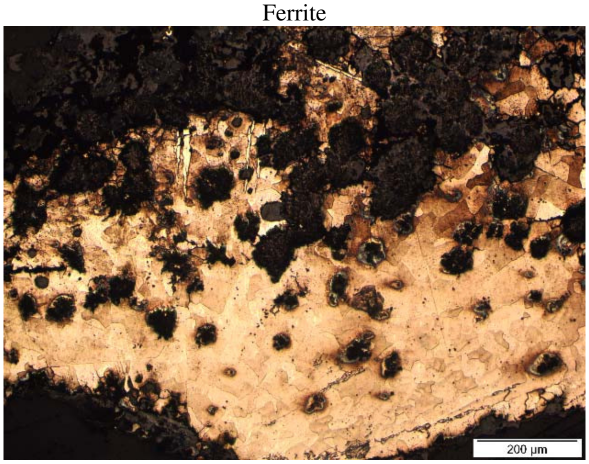
Appendix D- Photomicrograph of Samples from the Taicheng Cemetery



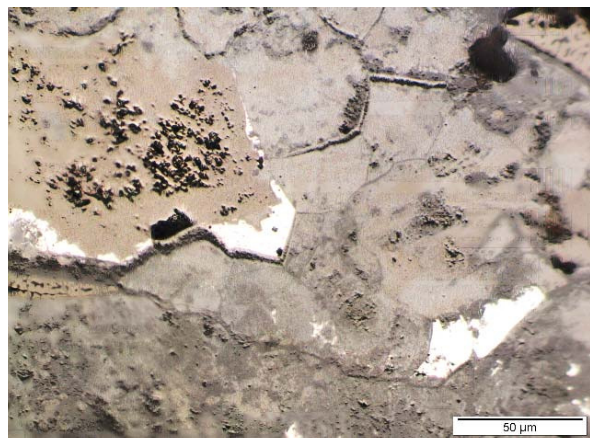
1 71312 SDM105:1 knife
Ferrite



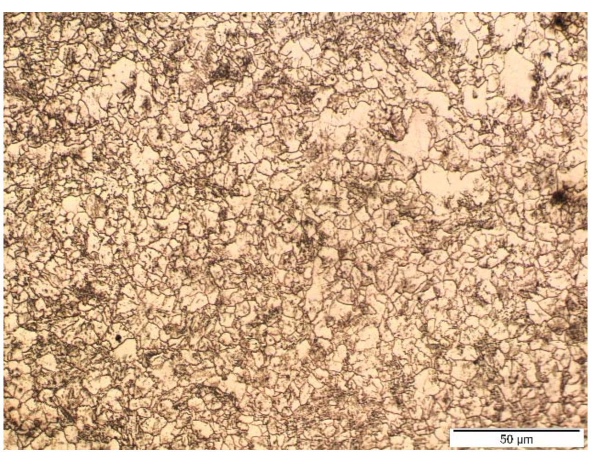
2 71312 SDM105:1 knife
Ferrite and SI



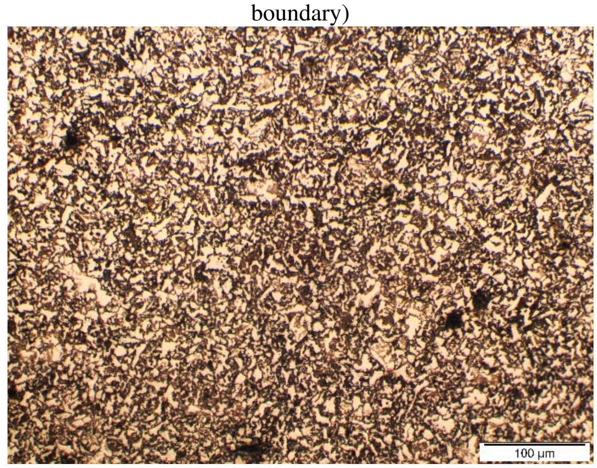
3 71303 SDM21:6 spade
Spherical graphite, ferrite and remains of ledeburit



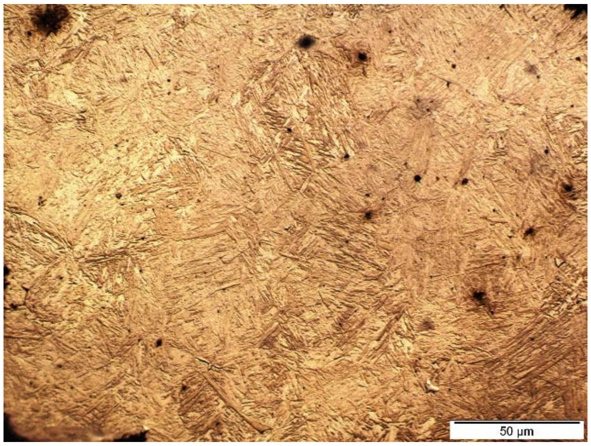
4 71301 SJM20:27 ring-pommel knife
Corroded remains of ferrite and pearlite (along the grain boundary)



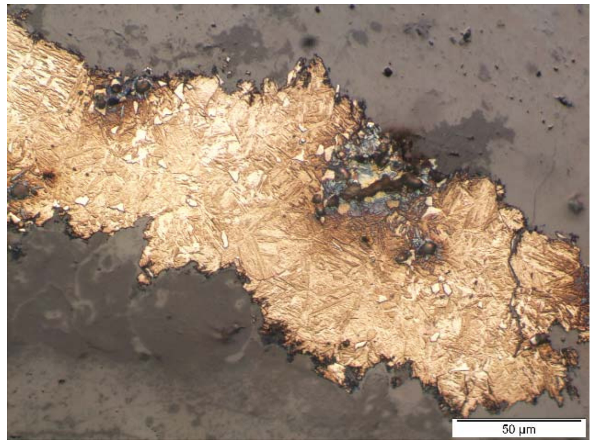
5 71102 SJM51:3 ring-pommel knife
Ferrite



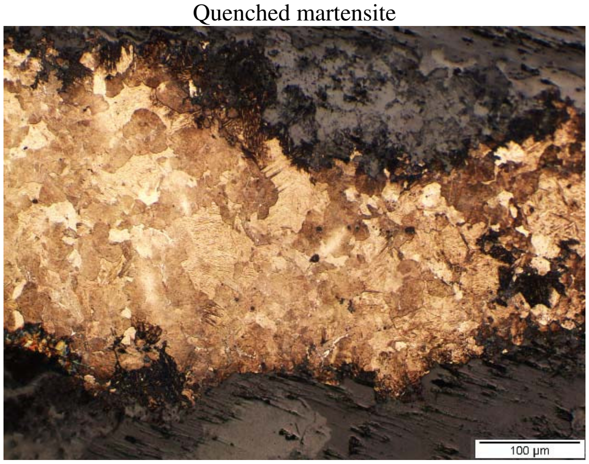
6 71305 SJM28:2 ring-pommel knife
Ferritic pearlite



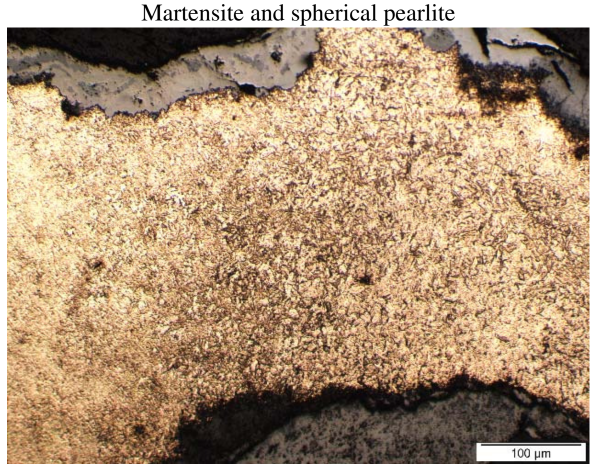
7 71105 JM31:8 ring-pommel knife
Quenched martensite



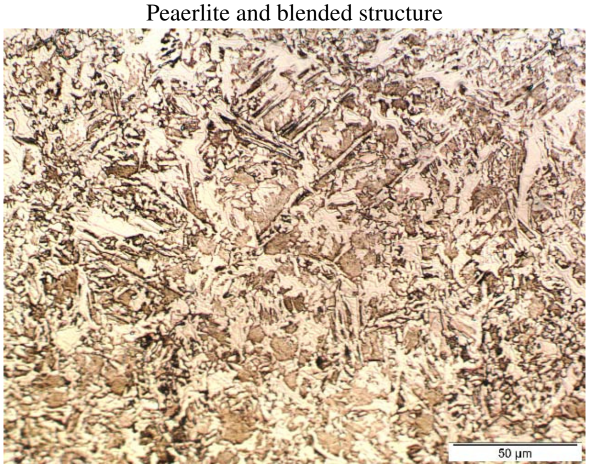
8 71105 JM31:8 ring-pommel knife
Martensite and spherical pearlite



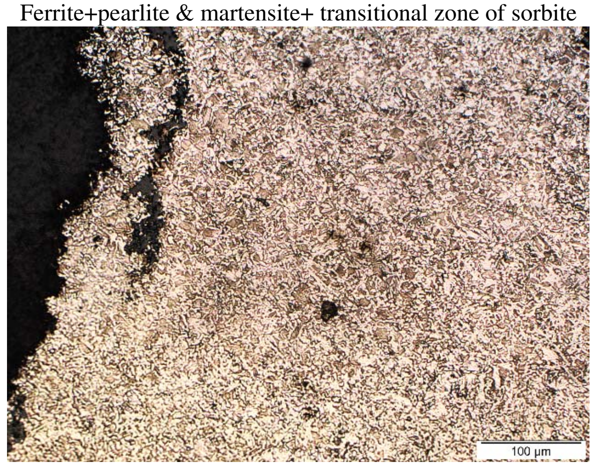
9 71300 SDM1:11 sword?
Peaerlite and blended structure



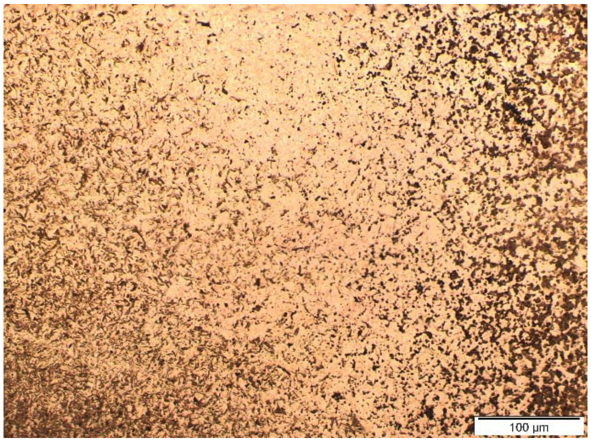
10 71311 SJM66:12 ring-pommel knife (tip-end)
Ferrite+pearlite & martensite+ transitional zone of sorbite



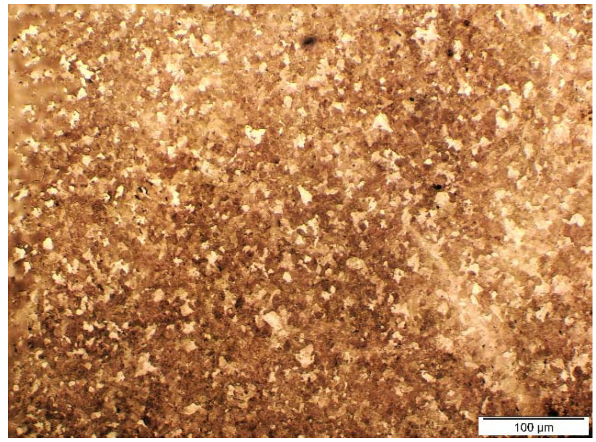
11 71311 SJM66:12 ring-pommel knife (core)
Widmanstatten structure consisting of pearlite and ferrite



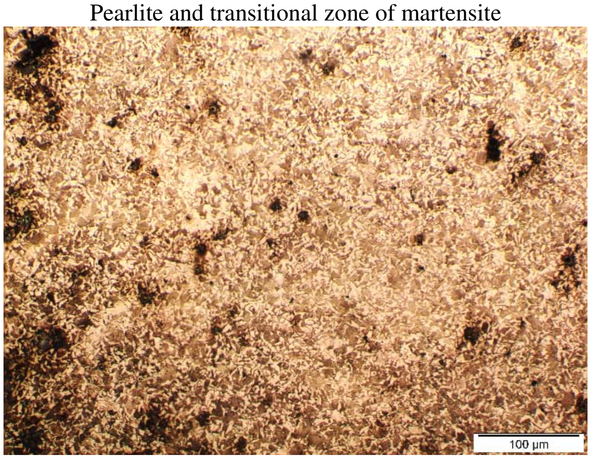
12 71311 SJM66:12 ring-pommel knife(rare edge)
Pearlitic ferrite



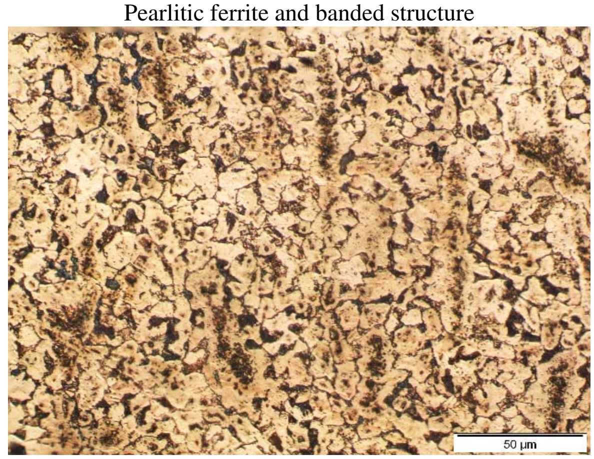
13 71313 SDM146:5 ring-pommel knife
Pearlite and transitional zone of martensite



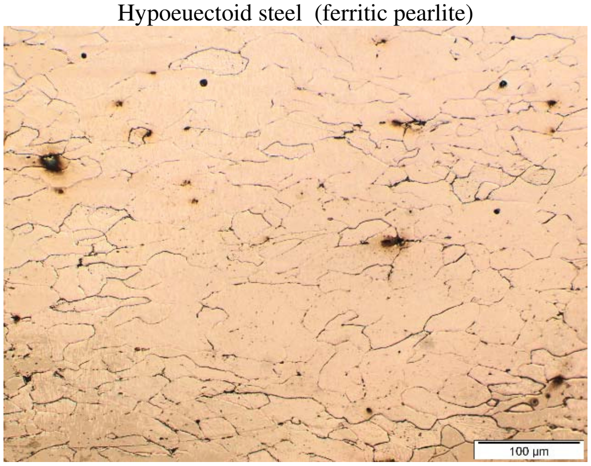
14 71313 SDM146:5 ring-pommel knife (edge)
Pearlitic ferrite and banded structure



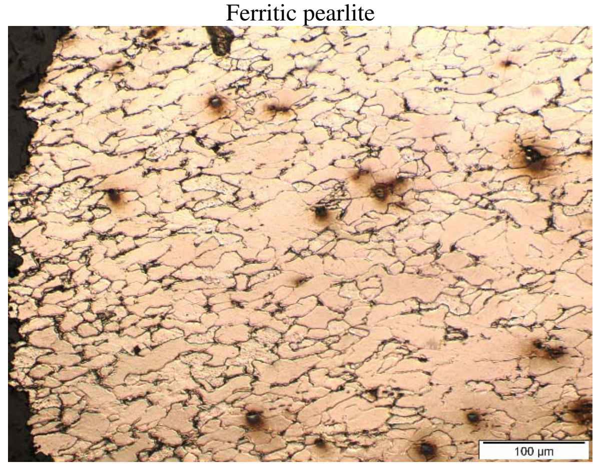
15 71313 SDM146:5 ring-pommel knife (rear edge)
Hypoeuectoid steel (ferritic pearlite)



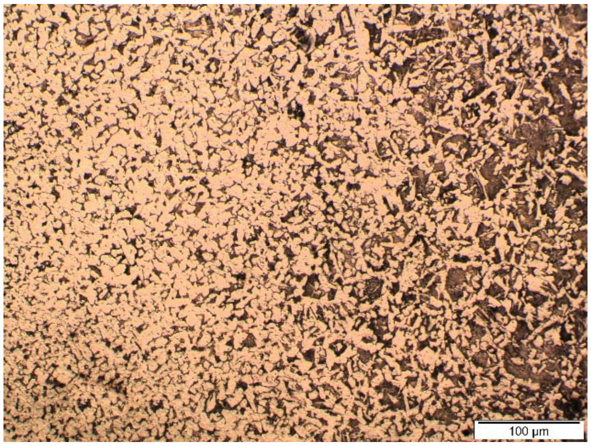
16 71314 SDM183:1 knife?
Ferritic pearlite



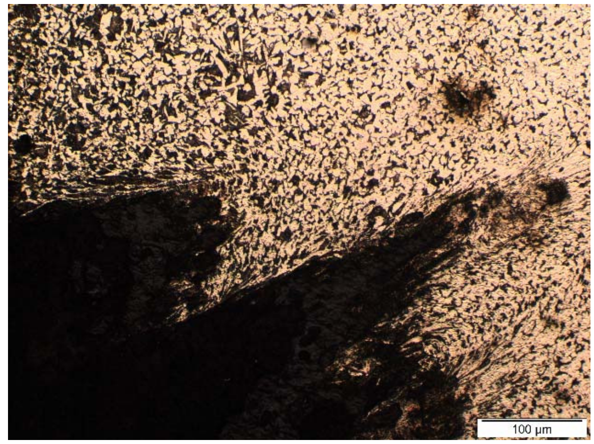
17 71102 SJM51:13 ring-pommel knife (core)
Ferritic grains that were deformed and elongated



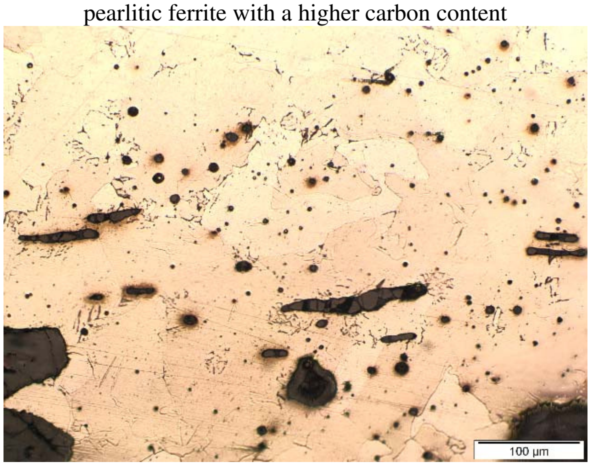
18 71102 SJM51:13 ring-pommel knife (edge)
Ferritic grains and pearlite that were deformed and elongated



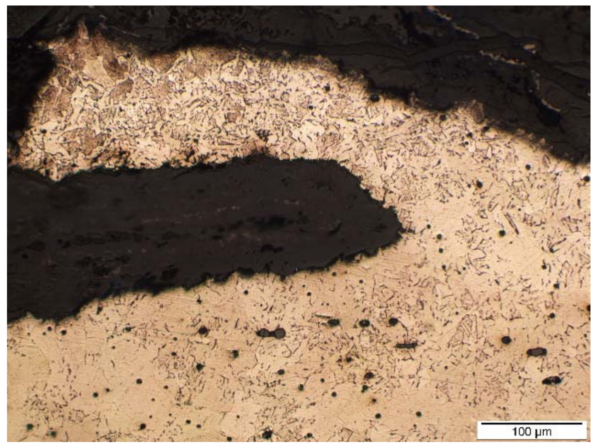
19 71316 SDM197:8 knife (edge)
Core (left side) is ferrlitic pearlite; edge (right side) is pearlitic ferrite with a higher carbon content



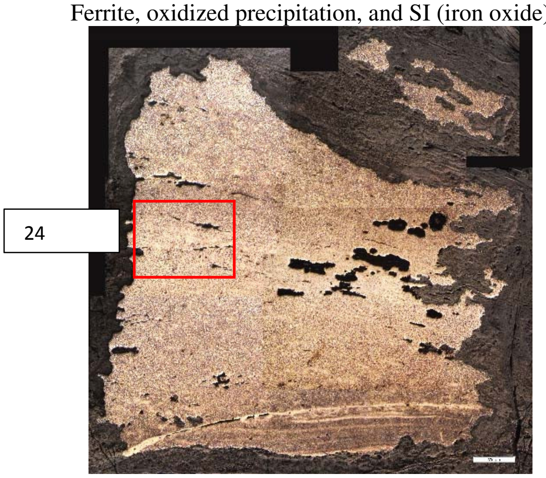
20 71316 SDM197:8 knife (rare edge)
Deformed rearlitic ferrite because of cold-working



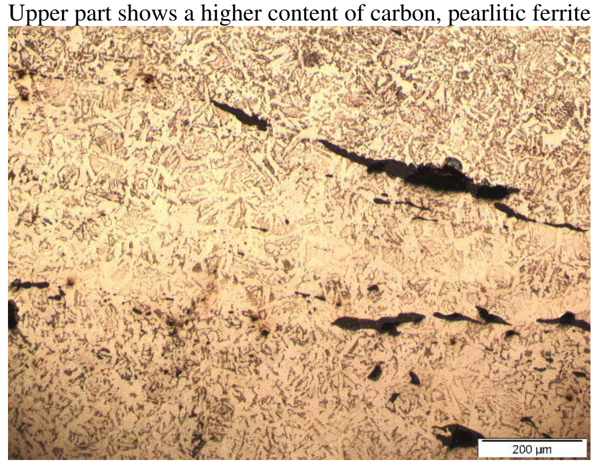
21 71321 SDM213:7 sword
Ferrite, oxidized precipitation, and SI (iron oxide)



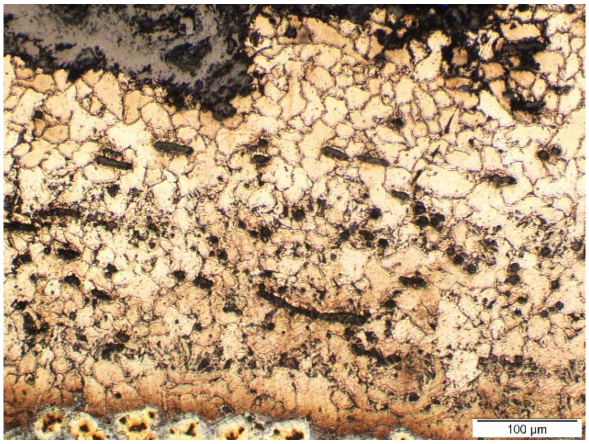
22 71321 SDM213:7 sword
Upper part shows a higher content of carbon, pearlitic ferrite



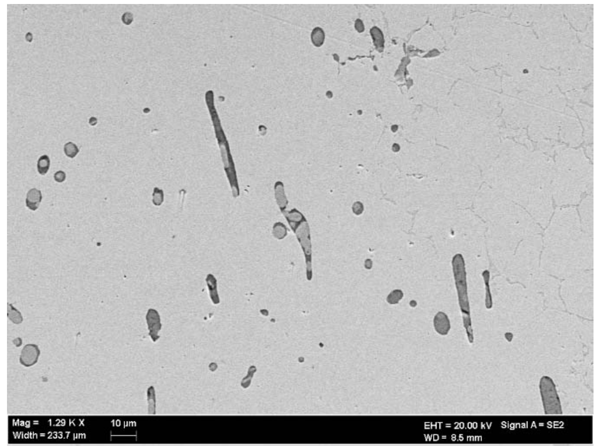
23 71309 SJM63:12 knife?
Mosaic image of cross section



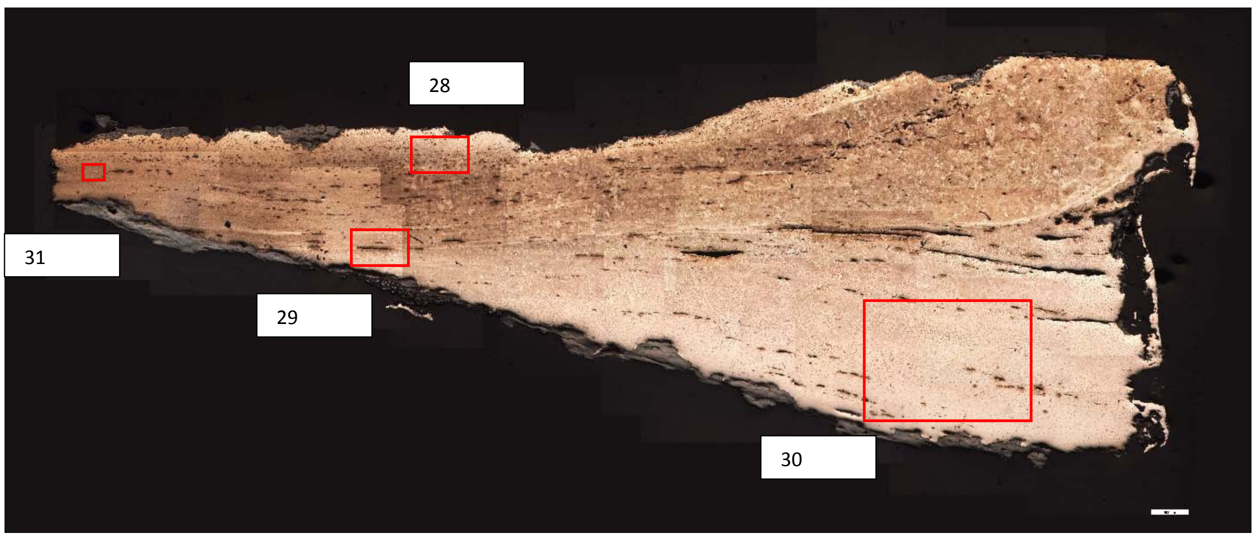
24 71309 SJM63:12 ring-pommel knife?
(Center) ferrite, pearlite, and trace of welding. Upper and lower parts are ferritic pearlite and Widmanstatten structure



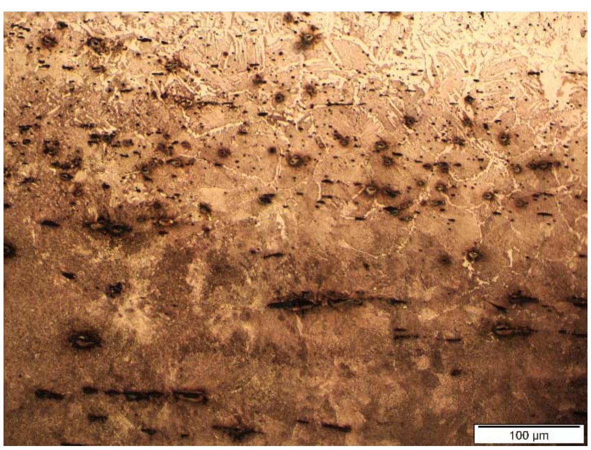
25 71304 SJM26:8 ring-pommel knife
Ferritic pearlite and SI



26 71304 SJM26:8 ring-pommel knife
Ferrite and the secondary image of SI

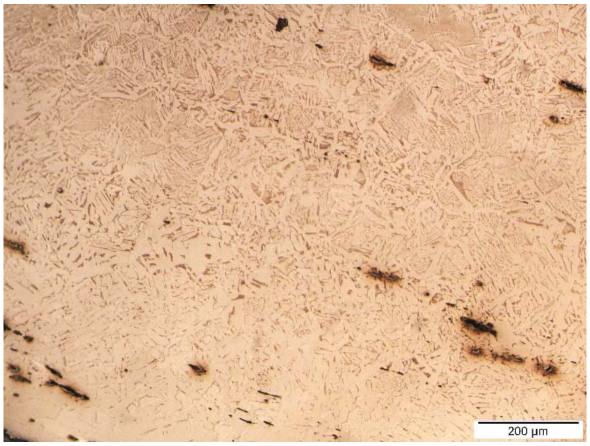


27 71306 SJM32:2 spade Mosaic image of cross section

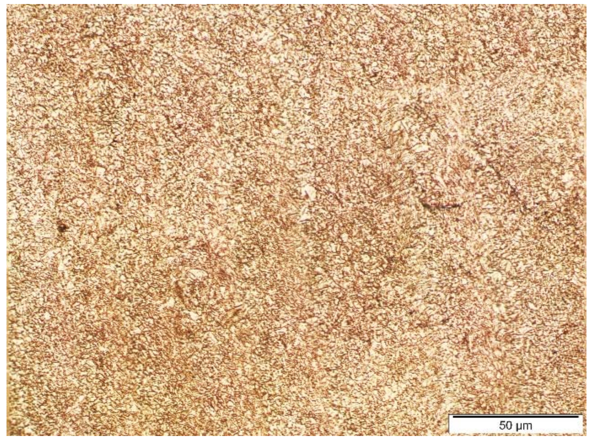


28 71306 SJM32：2 spade(the transition from the first to second layers)
Upper: ferritic pearlite and Widmanstatten structure, with spheroid SI. Lower: pearlite and elongated SI

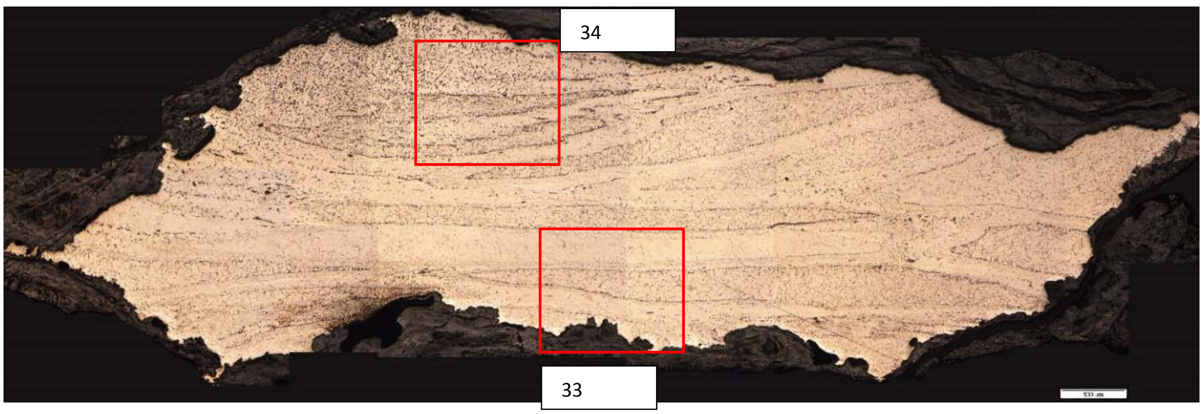
29 71306 SJM32：2 spade (the transition from the second to the third layers)
Upper: pearlite. Lower: pearlite and grid-like ferrite



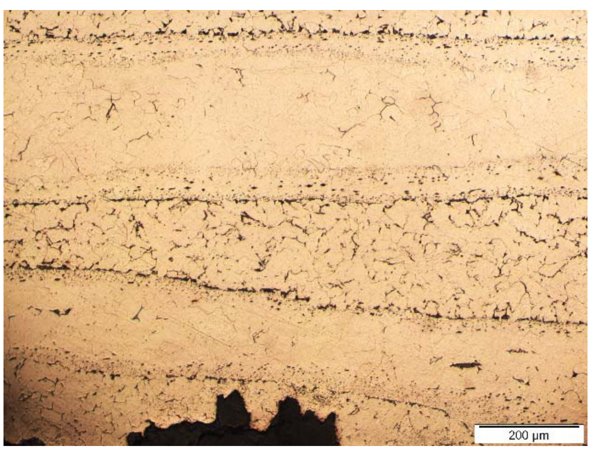
30 71306 SJM32：2 spade(The third layer)
Ferritic pearlite and SI, Upper part is Widmanstatten structure



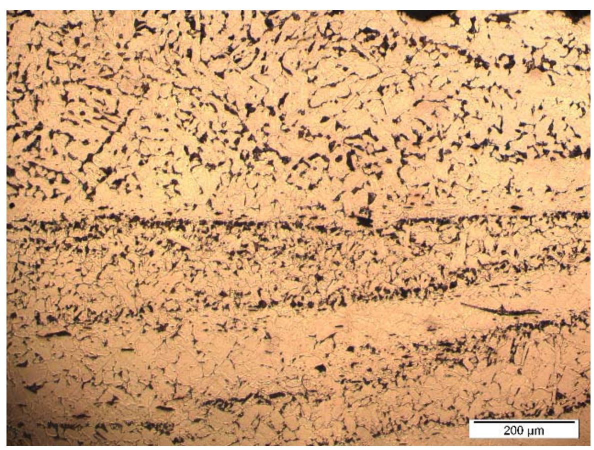
31 71306 SJM32：2 spade (tip-end)
Sphenoid pearlite



32 71320 SDM213:13 ji halberd Mosaic image of cross section

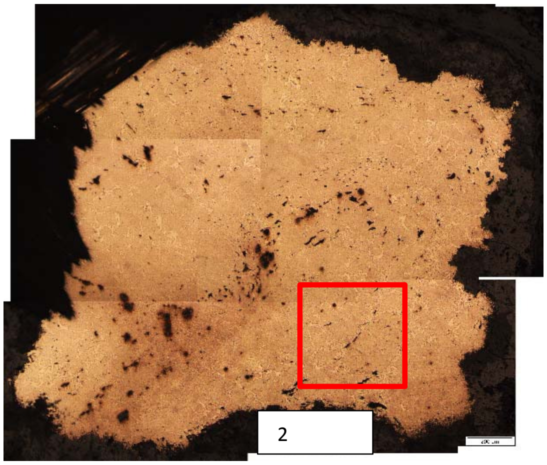


33 71320 SDM213:13 *ji* halberd
Alternative layers with different carbon contents. The major structure is ferrite with small amount of pearlite. SI in lower carbon zone was elongated

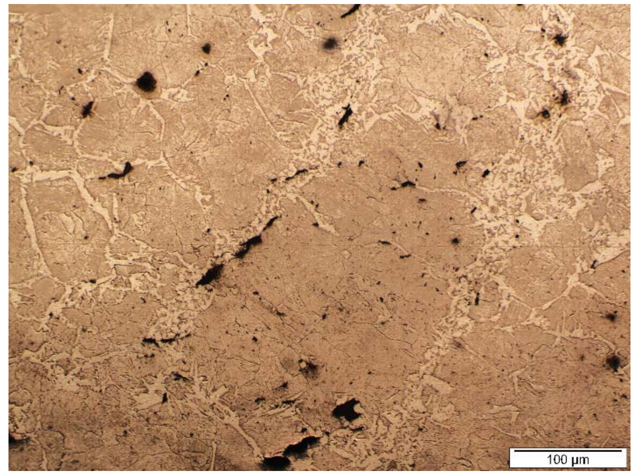


34 71320 SDM213:13 *ji* halberd
Upper part is ferritic pearlite with 0.2% of carbon contents. Lower part is ferritic pearlite with 0.1% of carbon contents. Ferritic grains belong to 3-4 grades with equal size.

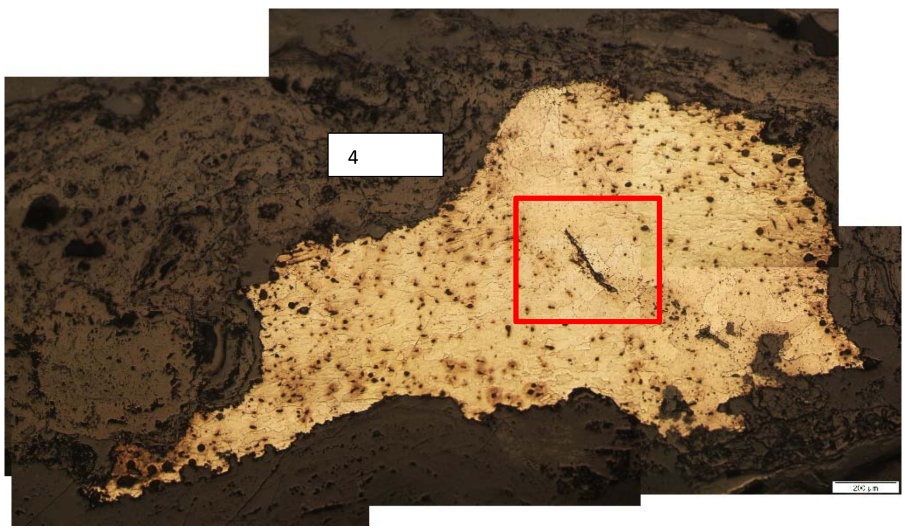
Appendix E- Photomicrograph of samples from the Wanli cemetery



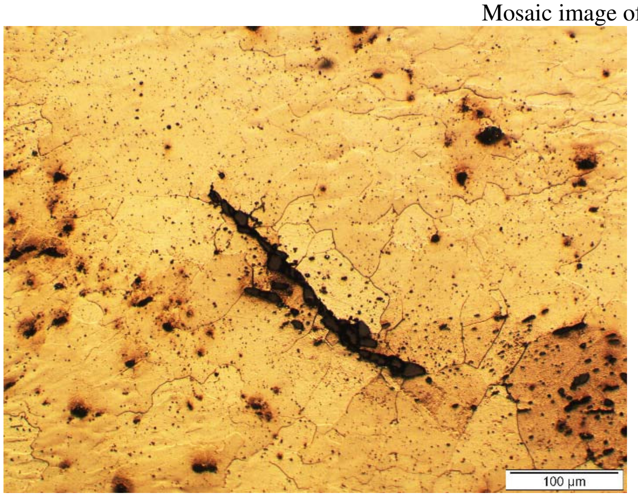
1 71351 05M1:10 fork
Mosaic image of cross section



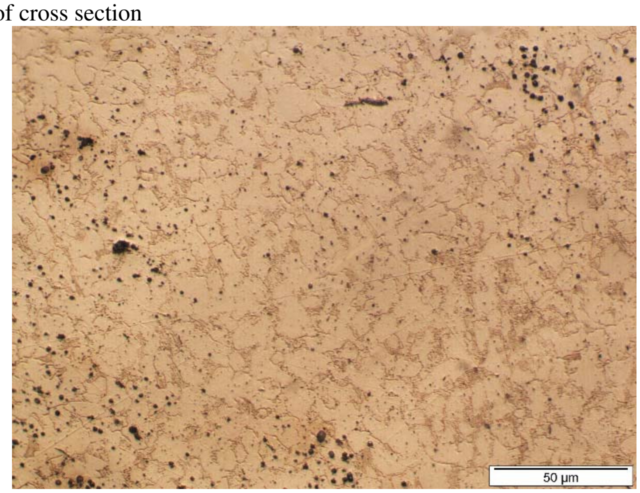
2 71351 05M1:10 fork
Pearlite, cementite and deformed SI



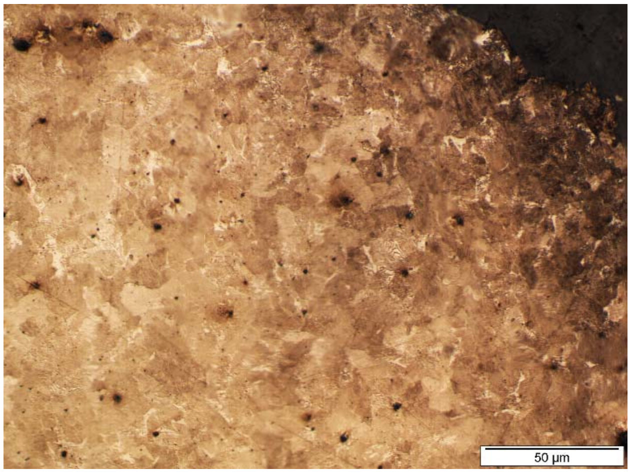
3 71359 M16:26 Ring-pommel knife
Mosaic image of cross section



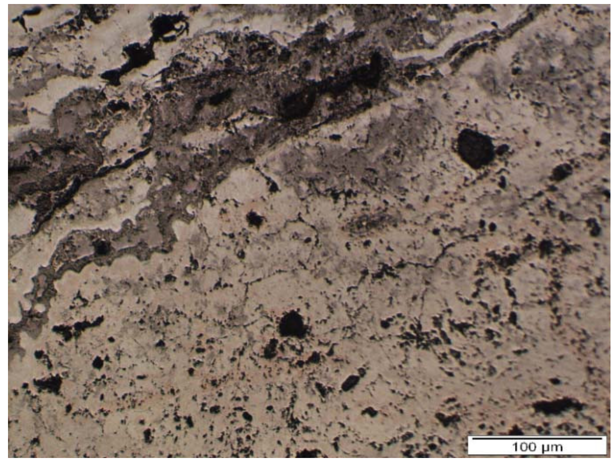
4 71359 M16:26 Ring-pommel knife
Ferritite grains with SI, showing the trace of welding



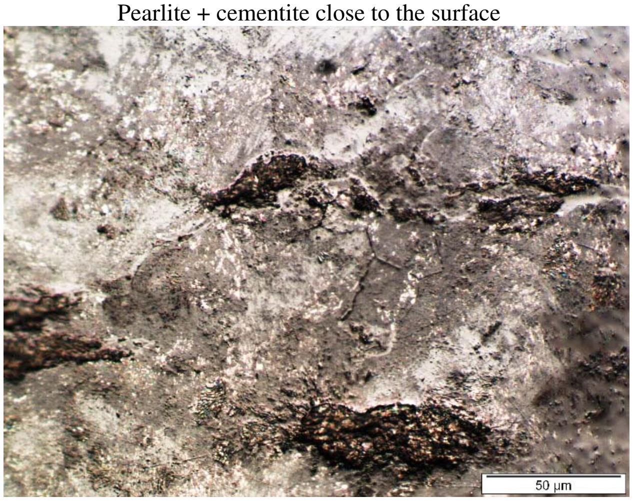
5 71355 M15:03 Ring-pommel knife
Pearlitic ferrite with homogeneous-size grains



6 71353 M14:11 Ring-pommel knife
Pearlite + cementite close to the surface



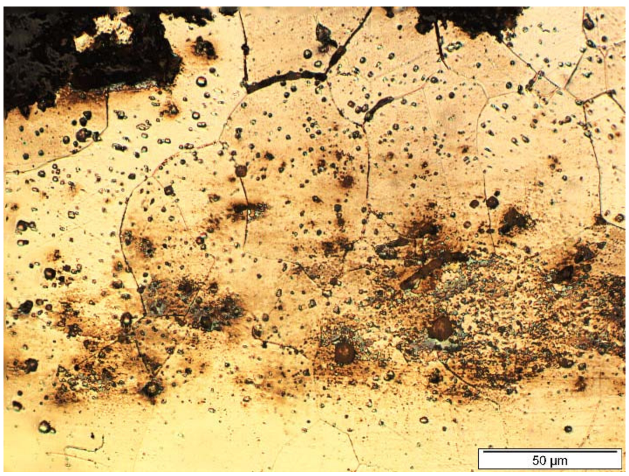
7 71358 M16:22 sword?
Corroded trace of pearlite and ferrite (wrought iron)



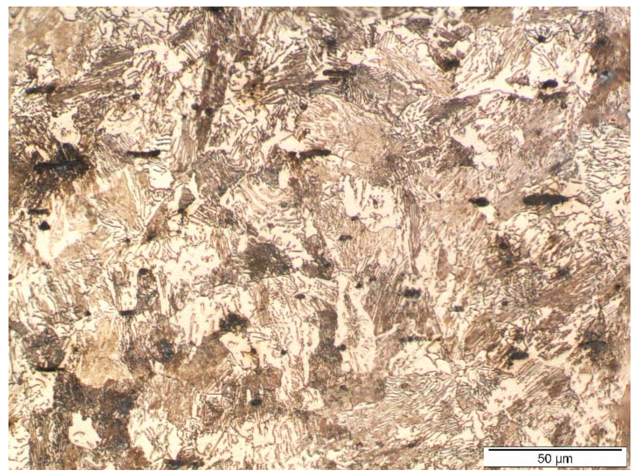
8 71352 M14:10 Ring-pommel knife
Corroded trace of pearlite and ferrite (wrought iron)

Appendix F- Photomicrograph of samples from the Wanli cemetery

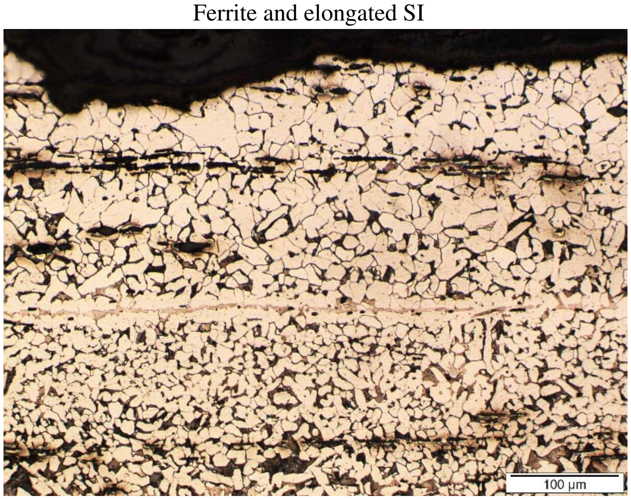
1 71341 2010SDM183:1 knife Mosaic image of cross section



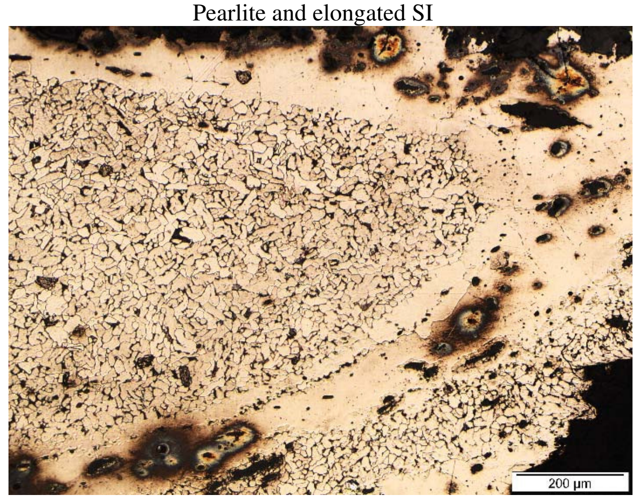
2 71341 2010SDM183:1 knife
Ferrite and elongated SI



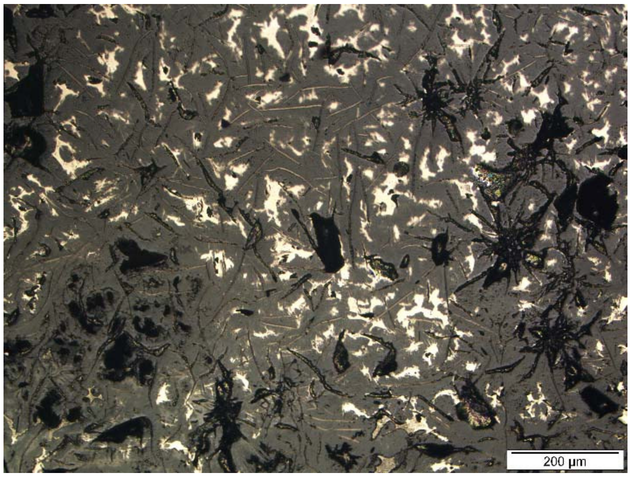
3 71327 09WLM110：1 ring-pommel knife
Pearlite and elongated SI



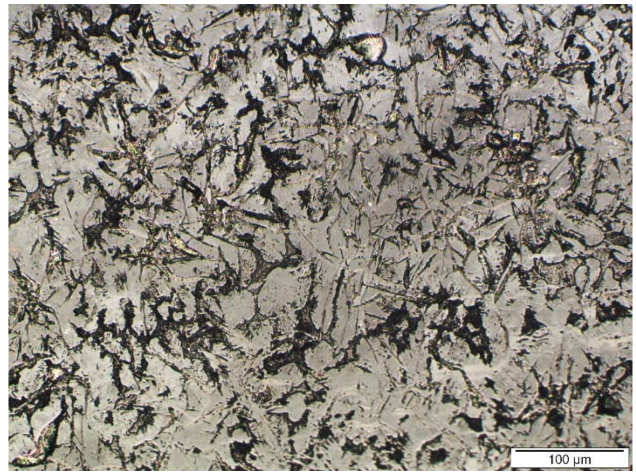
4 71332 (core) 09WLM109：14 cha spade
Ferrite and pearlite; center shows traces of welding



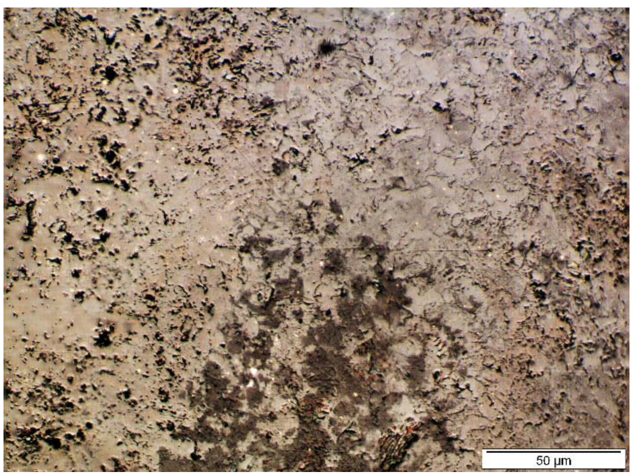
5 71332 (rear edge) 09WLM109：14 cha spade
Alternative layers of pearlite and ferrite (from inner to outer)



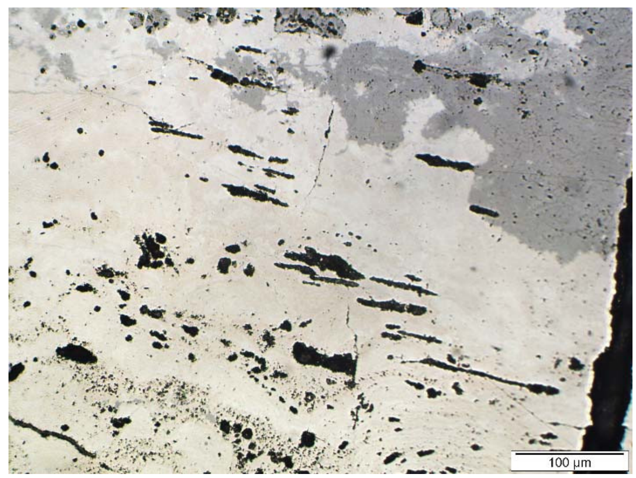
6　71326　09WLM75：4　iron caldron
Molt pig iron with graphite



7　71333　09WLM72：11　iron burner
Molt pig iron with graphite



8　71336　09WLM110：6　ring-pommel knife
Trace of corroded ferrite and pearlite (wrought iron)



9　71323　09WLM72：11　knife
Trace of wrought iron

Appendix G-Table G1. SEM-EDS Results of SI in Iron Objects from the Three Cemeteries

Lab no	method	slag location	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO
71327	area(most of the SI)	s1	1.6	1.6	6.8	33.7	2.2		2.2	6.3	0.5	0.4	43.7
71327	area(most of the SI)	s2	3.5	0.3	0.2	1.1	7.2		0.3	0.9		0.2	85.7
71327	area(most of the SI)	s3	2.3	1.0	2.5	8.0	7.6		0.9	1.3	0.2	0.4	75.6
71327	area(most of the SI)	s4	0.5	2.1	6.0	34.2	0.3		1.3	21.0	0.6	0.4	33.2
71327	area(most of the SI)	s5	0.6	1.2	4.3	24.3	1.2		1.3	10.8	0.4	0.6	54.6
71327	area(most of the SI)	s6	0.3	2.1	3.2	32.4	1.9		0.2	25.4	0.1	0.1	34.0
71327	area(most of the SI)	s7	1.5	2.2	4.4	16.8	2.0	1.3	1.4	6.2	0.6	0.9	60.9
71327	area(most of the SI)	s8		0.3	1.4	43.2	0.8	0.2	0.2	35.4	0.1	0.1	18.2
71327	area(most of the SI)	s9	0.3	1.0	3.2	9.7	0.9	0.5	0.8	4.6	0.4	0.4	77.4
71327	area(most of the SI)	s10	0.9	2.7	8.0	42.2	1.0	0.1	2.4	23.0	0.6	0.3	18.6
71327	area(most of the SI)	s11		0.5	0.6	3.6	2.4	0.7	0.4	2.3	0.2	0.5	87.9
71327	area(most of the SI)	s12	0.6	2.1	6.0	37.2	0.9		1.5	19.4	0.2	0.3	31.7
71327	area(most of the SI)	s13	0.8	1.9	6.7	42.5	0.9		2.0	23.4	0.2	0.2	21.3
71327	area(most of the SI)	s14	0.2	1.1	1.6	34.2	4.0		0.3	32.7	0.4	0.2	25.2
71327	area(most of the SI)	s15	0.2	0.3	1.1	70.5	0.4	0.3	0.4	1.9	0.6	0.3	23.7
71327	area(most of the SI)	s16	1.5	1.9	3.8	16.1	1.6	1.3	1.3	3.2	0.5	0.7	66.5
71327	area(most of the SI)	s17	2.6	2.1	6.6	32.8	5.1		2.1	13.1	0.3	0.9	34.0
71327	area(most of the SI)	s18	0.2	0.6	0.9	6.3	1.5	0.5	0.4	3.0	0.2	0.3	85.9
71327	area(most of the SI)	s19	0.7	3.4	7.9	5	0.6		2.0	27.2	0.4	0.2	7.7
71327	area(most of the SI)	s20	0.6	1.7	6.6	38.3	0.9	0.2	1.7		0.5	0.4	28.6
71327	area(most of the SI)	s21	0.8	2.9	8.8	47.2	0.5	0.2	3.0	25.7	0.6	0.5	9.7
71351	area(most of the SI)	s1	0.8	2.9	6.6	52.4	0.2	0.2	4.1	23.2	0.7	0.7	7.8
71351	area(most of the SI)	s2	0.6	3.5	6.5	50.4	0.2	0.3	2.8	28.6	0.5	0.4	6.1
71351	area(most of the SI)	s3	0.6	3.3	6.6	52.0	0.2	0.2	3.1	25.5	0.7	0.7	6.6
71351	area(most of the SI)	s4	1.0	3.1	6.6	53.7	0.1	0.3	3.8	24.8	0.6	0.6	5.1
71351	area(most of the SI)	s5	0.7	3.1	6.6	51.4	0.2	0.2	3.2	23.0	0.4	0.4	10.7

Table G.1 (Continued)

71351	area(most of the SI)	s6	0.6	2.9	1.8	3.0	7.6	0.6	0.4	24.0	0.8	1.0	56.0
71351	area(most of the SI)	s7		0.6	0.7	4.6	0.7	0.5	0.2	1.8	0.2	0.7	89.1
71351	area(most of the SI)	s8		1.5	1.3	9.1	0.7	0.1	0.4	3.4	0.3	0.6	82.1
71351	area(most of the SI)	s9		1.0	1.0	11.2	1.6	0.3	0.3	4.5	0.2	0.6	78.8
71351	point/mineral in SI	s9		1.7	1.7	20.7	4.4		0.7	8.5	0.1	0.6	61.1
71351	point/mineral in SI	s9		0.6	0.8	2.7	0.4	0.3	0.2	0.9	0.2	0.5	92.9
71351	area(most of the SI)	s10		2.8		0.4		0.3		2.6	0.2	0.8	92.5
71351	area(most of the SI)	s11	0.3	0.4	0.4	1.5	3.8	0.2	0.3	14.9	0.4	0.9	74.9
71351	area(most of the SI)	s12		0.6	1.0	11.5	1.5	0.2	0.6	4.6	0.2	0.6	78.5
71351	point/mineral in SI	s12	0.1	0.7	1.9	25.7	3.3	0.3	1.3	10.4	0.3	0.8	54.6
71351	area(most of the SI)	s13	0.3	1.6	3.8	36.7	2.0		1.4	16.1		1.3	36.8
71351	area(most of the SI)	s14	0.3	2.6	5.3	43.9	0.6	0.2	3.8		0.5	1.1	21.4
71351	area(most of the SI)	s15	0.4	1.3	3.9	34.0	3.7	0.2	1.4	14.6	0.4	1.1	38.6
71351	point/mineral in SI	s15	0.1	2.7	1.7	32.9	3.2		0.6	11.0		1.3	46.4
71351	point/mineral in SI	s15	0.5	0.6	6.9	38.3	2.9	0.8	2.0	18.6	0.4	0.7	28.2
71351	area(most of the SI)	s16	0.1	0.3	2.0	13.1	0.1	0.2		0.7	0.2	0.3	82.7
71351	point/mineral in SI	s16			0.3	1.3	0.2	0.3		0.3		0.4	96.5
71351	area(most of the SI)	s17	0.7	3.3	6.6	52.4	0.2	0.3	3.4	27.1	0.6	0.7	4.5
71351	area(most of the SI)	s18	0.7	3.3	6.9	51.4	0.3	0.3	3.8	25.9	0.6	0.6	5.9
71351	area(most of the SI)	s19	0.5	2.6	5.1	32.7	0.3	0.3	1.9	13.0	0.5	0.5	42.4
71351	area(most of the SI)	s20	0.5	3.5	6.3	45.6	0.4	0.3	2.7	24.6	0.6	0.6	14.6
71332	area(most of the SI)	s1	0.6	2.9	8.7	47.8	1.1		3.2	26.8	0.6	0.6	7.6
71332	area(most of the SI)	s2	0.8	1.5	7.3	38.9	1.2		1.2	5.3	0.4	0.2	43.2
71332	point/mineral in SI	s2	1.2	0.6	12.7	45.3	2.2		2.1	10.9	0.6	0.1	24.4
71332	point/mineral in SI	s2	0.2	2.8	2.1	33.7	0.3		0.4	2.1	0.3	0.3	57.4
71332	area(most of the SI)	s3	0.7	1.8	7.3	38.0	1.7		1.1	5.6	0.4	0.3	43.0
71332	point/mineral in SI	s3	1.0	0.7	10.8	42.9	3.4	0.5	1.9	10.4	0.9	0.2	26.4
71332	point/mineral in SI	s3	0.2	3.2	2.6	35.4	0.8		0.5	2.7	0.2	0.2	53.8
71332	area(most of the SI)	s4	0.6	2.0	5.4	30.2	4.2		1.6	17.2	0.5	0.6	37.1

Table G.1 (Continued)

71332	area(most of the SI)	s5	0.6	1.2	3.5	13.8	0.9	0.6	0.9	4.7	0.5	0.5	71.7
71332	area(most of the SI)	s6	0.8	2.1	7.0	40.1	2.0		2.0	12.4	0.7	0.7	31.3
71332	area(most of the SI)	s7	0.9	1.4	9.0	40.2	2.3	0.2	1.5	7.0	0.7	0.3	36.1
71332	area(most of the SI)	s8	1.2	1.5	9.1	50.8		0.1	2.8	7.6	0.7	1.1	24.8
71332	area(most of the SI)	s9	0.3	6.2	2.5	36.8	1.1		0.5	2.6	0.2	0.3	49.4
71332	point/mineral in SI	s9	0.3	6.8	1.7	35.2	0.9		0.3	1.7	0.2	0.4	52.4
71332	point/mineral in SI	s9	0.9	0.9	9.7	41.1	1.9		1.3	8.3	0.6	0.2	35.0
71332	area(most of the SI)	s10	0.8	2.1	8.6	49.9	0.7		2.2	10.9	0.7	0.6	22.7
71332	area(most of the SI)	s11	0.8	1.2	5.3		0.4		1.4	6.4	0.7	2.0	50.8
71332	area(most of the SI)	s12	0.7	0.8	5.1	24.7	1.0	0.2	1.1	3.2	0.5	0.5	61.6
71332	area(most of the SI)	s13	0.5	1.7	6.1	35.1	1.8		1.0	4.9	0.4	0.3	47.6
71332	point/mineral in SI	s13	1.0	0.6	11.7	40.2	2.6	0.2	1.9	8.2	0.6	0.3	31.9
71332	point/mineral in SI	s13	1.2	0.9	9.8	36.1	4.9		1.6	8.8	0.7	0.3	35.4
71332	point/mineral in SI	s13		2.7	1.0	32.0	0.7		0.3	2.0	0.3	0.4	60.2
71332	area(most of the SI)	s14	0.3	1.2	3.3	17.0	3.4		0.8	2.0	0.3	0.5	70.7
71332	point/mineral in SI	s14		0.3	0.6	0.7	0.2	0.2	0.1	0.1	0.6	0.4	96.1
71332	point/mineral in SI	s14	1.3	0.9	0.3	6.2	28.6		0.9	31.8	0.1	0.4	29.1
71332	point/mineral in SI	s14	1.5	0.8	0.4	4.4			0.8	29.0		0.3	32.9
71332	area(most of the SI)	s15	0.4	1.3	6.1	41.6	3.2		0.6	11.4	0.4	1.5	33.3
71332	point/mineral in SI	s15	0.5	1.0	7.0	40.2	3.7		0.6	13.7	0.5	0.8	31.8
71332	point/mineral in SI	s15	0.2	2.7	4.4	44.3	1.8		0.1	17.5	1.1	1.3	25.3
71332	point/mineral in SI	s15		2.2	3.7	37.4	1.6		0.3	4.9		2.1	47.5
71332	area(most of the SI)	s16	0.8	2.2	8.4	44.0	0.8		1.5	6.6	0.5	0.3	34.3
71332	point/mineral in SI	s16	1.0	1.0	11.6	50.8	1.3		2.0		0.6		21.6
71332	point/mineral in SI	s16	0.9	0.7	11.3	49.6	1.6		2.0	11.6	0.8	0.2	21.0
71332	area(most of the SI)	s17	0.7	1.9	6.6	38.1	1.2		1.1	5.2	0.3	0.2	44.4
71332	point/mineral in SI	s17	1.3	0.2	10.2	38.9	4.7		2.5	13.0	0.8	0.2	27.5
71332	point/mineral in SI	s17	1.3	0.6	10.7	37.9	2.3		2.0	8.7	0.5	0.2	35.8
71332	area(most of the SI)	s18	0.4	0.8	1.3	12.9	1.8		0.3	1.3	0.2	0.3	80.4

Table G.1 (Continued)													
71332	point/mineral in SI	s18	1.6	0.8	1.7		23.3		1.4	22.8	0.3	0.3	37.3
71332	area(most of the SI)	s19	0.2	0.3		0.9	39.7		0.2	39.6		0.5	18.3
71332	area(most of the SI)	s20	0.3	1.9	3.4	22.3	12.9		1.2	12.5	0.1	0.6	44.0
71332	area(most of the SI)	s21	0.3	0.4	1.5	6.8	19.4	0.4	0.3	5.5	0.2	0.5	63.9
71332	area(most of the SI)	s22	0.6	1.5	5.1	23.9	8.1		2.6	15.8	0.3	0.3	41.6
71332	point/mineral in SI	s22	1.2	0.2	18.2	35.7	2.5		16.2	8.1		0.2	16.9
71332	point/mineral in SI	s22		4.1	0.3	30.1	2.7		0.3	8.2	0.1	0.5	53.3
71332	area(most of the SI)	s25	0.5	1.4	4.0	19.1	13.3		1.4	17.1	0.4	0.6	41.3
71332	area(most of the SI)	s26	0.2	0.4	0.8	10.9	8.6		0.2	1.3	0.1	0.4	76.4
71332	point/mineral in SI	s26		0.8	0.3	28.7	2.7			0.1	0.1	0.4	66.5
71332	point/mineral in SI	s26			0.6	0.6	0.5	0.4	0.2	0.3	0.3	0.5	95.3
71332	area(most of the SI)	s27	0.2	0.5	0.9	14.5	22.0	0.1	0.4	4.8	0.3	0.7	55.2
71332	area(most of the SI)	s28	0.2	0.6	3.4	17.8	6.8		0.8	5.1	0.5	2.1	62.0
71332	point/mineral in SI	s28	1.0	0.3	0.5	1.4	28.1		1.0	30.9	0.2	0.8	35.4
71332	area(most of the SI)	s29	0.7	0.9	4.3	18.1	3.4		1.3	6.4	0.2	0.3	64.3
71332	point/mineral in SI	s29	0.7	0.9	4.3	26.5	1.8		1.3	6.5	0.2	0.5	57.1
71332	point/mineral in SI	s29	1.4	0.2	9.3	19.0	13.5		6.5	19.8	0.2	0.3	29.1
71332	point/mineral in SI	s29	0.1	2.0	0.4	28.7	2.6		0.3	6.4	0.2	0.5	58.5
71332	area(most of the SI)	s30	0.7	0.4	2.2	17.0	21.4		1.0	20.6	0.1	1.5	34.6
71332	area(most of the SI)	s31	0.7	2.0	7.9	47.7	1.9		2.6	13.8	0.4	0.4	22.2
71332	point/mineral in SI	s31	1.1	0.6	9.9	48.2	1.8		3.6	10.9	0.3	0.4	23.2
71332	area(most of the SI)	s32	0.4	2.1	6.7	39.1	7.4		1.6	24.3		0.3	18.0
71332	area(most of the SI)	s33	0.3	0.4	1.3	16.0	20.5	0.1	0.3	3.9	0.2	0.6	55.8
71332	area(most of the SI)	s34	0.3	0.5	1.8	13.5	18.9		0.2	1.5	0.5	0.6	59.2
71332	area(most of the SI)	s35	0.3	0.9	2.0	14.0	0.9	0.2	0.6	2.1	0.3	0.3	78.1
71332	point/mineral in SI	s35		1.9	0.2	31.8	0.4		0.2	2.5		0.4	62.3
71332	point/mineral in SI	s35		0.1	0.6	0.8	0.2	0.3	0.2	0.3	0.4	0.4	95.9
71332	area(most of the SI)	s36	0.2	0.7	0.3	23.5	9.9		0.1	0.3	0.2	0.2	64.2
71332	area(most of the SI)	s37	0.6	0.8	1.6	6.2	2.6		0.6	1.4	0.1	0.3	85.3

Table G.1 (Continued)													
71332	point/mineral in SI	s37	1.6	1.0	1.2	9.2	21.5		0.8	18.0		0.3	45.8
71332	area(most of the SI)	s39	0.3	0.6	1.1	16.9	16.6	0.3	0.2	1.9	0.1	0.4	61.1
71332	point/mineral in SI	s39	0.6	0.4	1.9	1.9	33.0	1.4	0.2	15.9	0.3	0.7	43.3
71332	area(most of the SI)	s40		0.3	0.4	3.2	38.5			31.2		0.6	25.6
71117	point/mineral in SI	s6				0.2	0.2	0.2			0.1	0.2	98.8
71117	point/mineral in SI	s6	0.1	0.2		0.2	0.2	0.2				0.2	98.6
71117	point/mineral in SI	s6				0.4	0.3	0.2	0.1		0.1	0.3	98.3
71117	point/mineral in SI	s6		0.1	0.2	0.3	0.3	0.3	0.2	0.1	0.2	0.3	98.0
71117	point/mineral in SI	s7		0.3	0.3	0.4	0.4	0.2	0.1		0.1	0.3	97.8
71117	point/mineral in SI	s7	0.2	0.2		0.3	0.5	0.3	0.2	0.2	0.2	0.3	97.6
71117	point/mineral in SI	s7		0.2	0.1	0.4	0.4	0.4	0.1	0.3	0.2	0.3	97.6
71117	point/mineral in SI	s7		0.3	0.4	0.3	0.4	0.3	0.1	0.2	0.1	0.3	97.6
71117	point/mineral in SI	s7		0.2	0.1	0.4	0.7	0.3	0.1	0.2	0.2	0.4	97.4
71117	point/mineral in SI	s1	0.4	0.4	0.4	0.6	0.2	0.3			0.2	0.3	97.2
71117	point/mineral in SI	s2	0.2	0.1	0.2	0.4	1.1	0.3		0.3	0.1	0.3	96.9
71117	point/mineral in SI	s1		0.3	0.4	0.6	0.5	0.6	0.2	0.2		0.2	96.9
71117	point/mineral in SI	s2	0.4	0.7	0.5	0.6	0.7	0.4	0.1	0.1	0.2	0.2	95.9
71117	point/mineral in SI	s2	0.5	0.7	0.6	0.8	0.8	0.6	0.1	0.1	0.1	0.3	95.4
71117	point/mineral in SI	s2	0.3	0.3		0.3	2.0	0.6	0.1	0.8	0.2	0.2	95.2
71117	point/mineral in SI	s2	0.6	1.0	0.7	0.9	1.3	0.2	0.2	0.2		0.3	94.5
71117	point/mineral in SI	s4	0.2	0.4	0.8	1.7	0.8	1.0	0.1	0.5		0.4	94.0
71117	point/mineral in SI	s3	0.2	0.3	1.9	2.4		0.2		0.5	0.2	0.4	94.0
71117	point/mineral in SI	s1	0.7	0.9	0.8	1.0	0.8	0.9	0.3	0.2	0.1	0.4	93.9
71117	point/mineral in SI	s4	0.4	0.5	0.6	1.7	0.3	0.9	0.2	0.7	0.4	0.6	93.8
71117	point/mineral in SI	s1	0.7	1.0	1.0	1.1	1.0	1.0	0.3	0.3	0.2	0.3	93.0
71117	point/mineral in SI	s2	0.8	0.8	1.0	1.3	2.3	0.3	0.3	0.4	0.3	0.4	92.1
71117	point/mineral in SI	s3	0.2	0.5	1.9	2.7	0.8	0.5	0.1	0.7	0.3	0.4	91.8
71117	point/mineral in SI	s7	1.4	0.7	0.6	1.3	1.9	1.3	0.2	0.5	0.2	0.3	91.5
71117	point/mineral in SI	s1	0.7	1.0	1.2	3.1	1.2	0.5	0.2	0.7	0.2	0.7	90.5

Table G.1 (Continued)

71117	point/mineral in SI	s3	0.4	0.6	0.8	2.5	2.7	0.3	0.2	2.8	0.2	0.3	89.3
71117	point/mineral in SI	s7	0.2	0.4	0.7	3.3	5.9		0.1	0.2		0.2	88.9
71117	point/mineral in SI	s7	0.2		0.6	3.2	6.4			0.2	0.2	0.3	88.7
71117	point/mineral in SI	s4	0.5	0.8	1.4	5.1	1.2	1.0	0.2	1.5	0.3	0.5	87.5
71117	point/mineral in SI	s6	0.7	0.7	2.2	2.4	4.5	0.3	0.1	2.1	0.2	0.4	86.3
71117	point/mineral in SI	s1	0.5	0.9	1.4	5.8	1.7	0.6	0.2	1.9	0.4	0.6	85.9
71117	point/mineral in SI	s3	0.4	0.5	0.9	3.5	3.7	0.3	0.2	3.9	0.4	0.5	85.7
71117	point/mineral in SI	s4	0.4	0.7	1.6	6.2	1.4	0.9	0.3	2.1	0.2	0.7	85.5
71117	point/mineral in SI	s6		0.4	0.7	9.0	7.3		0.3	1.9	0.2	0.7	79.5
71117	point/mineral in SI	s3	0.7	0.5	0.7	3.9	7.9	0.4	0.3	6.3	0.2	0.1	79.0
71117	point/mineral in SI	s6	0.5	0.5	5.7	5.5	6.6		0.2	3.1	0.4	0.4	77.1
71117	point/mineral in SI	s3	0.7	0.6	0.9	5.2	12.1	0.7	0.4	10.1	0.2	0.3	68.8
71117	point/mineral in SI	s4	0.6	0.8	6.0	15.5	1.6	0.6	0.4	4.5	0.9	0.4	68.8
71117	point/mineral in SI	s3	0.9	0.5	1.2	10.9	8.0	0.3	0.6	10.8	0.4	0.4	66.0
71117	point/mineral in SI	s4	0.6	0.8	6.9	17.1	1.6	0.3	0.4	5.3	0.9	0.5	65.5
71117	point/mineral in SI	s3	0.9	0.8	1.2	6.4	10.9	1.1	0.5	12.6	0.2	0.5	65.0
71117	point/mineral in SI	s3	0.7	0.5	0.5	5.8	12.2	0.2	0.6	15.3	0.3	0.4	63.6
71117	point/mineral in SI	s3	1.0	0.5	1.4	11.3	9.2	0.5	0.5	11.5	0.3	0.4	63.5
71117	point/mineral in SI	s6	0.7	0.6	0.6	11.5	16.1		0.4	7.0	0.2	0.8	62.1
71117	point/mineral in SI	s6	0.4	0.5	0.4	8.0	19.8		0.5	10.2		0.7	59.3
71117	point/mineral in SI	s2	0.2	0.4	1.0	10.4	22.9	0.4	0.5	8.3	0.2	1.1	54.6
71117	point/mineral in SI	s2		0.5	0.9	4.7	27.2	0.1	0.5	12.4	0.4	1.1	52.1
71117	point/mineral in SI	s4	0.7	1.1	5.8	25.4	4.4	0.2	1.2	9.0	0.5	1.3	50.3
71117	point/mineral in SI	s4	0.8	0.8	6.1	26.1	4.4	0.1	1.4	9.5	0.4	1.0	49.4
71117	point/mineral in SI	s2		0.4	2.9	6.8	27.8	0.3	0.7	11.5	0.1	1.0	48.5
71117	point/mineral in SI	s6	0.4	0.7	0.4	8.1	25.8	0.2	0.4	15.4	0.1	0.8	47.7
71117	point/mineral in SI	s2	0.2	0.7	2.3	6.3	29.4	0.5	0.7	13.0		1.0	45.9
71117	point/mineral in SI	s3	1.1	0.7	1.1	8.1	25.0	0.3	0.6	23.3	0.2	0.4	39.3
71117	point/mineral in SI	s3	1.1	0.8	1.4	8.2	24.2	0.5	0.6	23.9		0.3	38.9

Table G.1 (Continued)

71117	point/mineral in SI	s3	0.9	0.7	0.4	3.1	32.8	0.1	0.6	33.8	0.1	0.2	27.2
71117	point/mineral in SI	s3	1.1	0.8	0.4	3.3	33.1	0.1	0.6	34.0	0.2	0.2	26.1
71117	point/mineral in SI	s1	0.3	0.5	0.3	4.1	34.8		1.0	32.6	0.2	0.4	25.8
71117	point/mineral in SI	s1	0.4	0.6	0.3	3.6	36.1		1.2	35.0	0.3	0.3	22.2
71117	point/mineral in SI	s1	0.3	0.3	0.2	3.1	37.0		1.0	36.4		0.4	21.2
71117	point/mineral in SI	s1	0.2	0.4	0.3	2.9	38.1	0.1	1.2	35.9	0.3	0.4	20.2
71117	point/mineral in SI	s3	0.7	0.7	0.2	4.5	36.3	0.2	0.7	38.6		0.2	17.7
71117	point/mineral in SI	s3	0.6	0.7	0.2	4.0	36.7		0.6	40.7	0.2	0.3	16.0
71117	point/mineral in SI	s3	0.5	0.6	0.1	2.5	39.4		0.6	44.7	0.1	0.3	11.1
71117	point/mineral in SI	s3	0.6	0.7	0.2	2.2	39.9		0.6	45.2			10.5
71119	point/mineral in SI	s3				0.2	0.5	0.3	0.1	0.2	0.2	0.4	98.1
71119	point/mineral in SI	s3	0.6	0.7	0.6	1.0	1.1	0.9	0.1	0.2	0.1	0.2	94.3
71119	point/mineral in SI	s3	0.6	0.6	0.6	1.0	1.2	1.1	0.2	0.2	0.1	0.2	94.1
71119	point/mineral in SI	s3	0.9	1.1	1.1	1.9	1.1	0.7	0.2	0.2	0.2	0.3	92.1
71119	point/mineral in SI	s3	1.0	1.0	1.0	1.4	1.4	1.6	0.4	0.4	0.4	0.3	91.2
71119	point/mineral in SI	s3	0.9	1.1	1.2	2.6	1.5	1.1	0.5	0.6	0.3	0.4	89.8
71119	point/mineral in SI	s1	0.2	0.2	6.1	13.4	3.1		0.3	0.2	0.1	0.3	76.1
71119	point/mineral in SI	s1	0.2	0.2	1.8	17.3	4.4	0.3	0.2	0.5	0.2	0.4	74.6
71119	point/mineral in SI	s1		0.2	3.4	21.2	5.3	0.1	0.2	0.7	0.3	0.4	68.2
71119	point/mineral in SI	s1	0.2	0.3	0.6	26.5	3.5		0.2	0.6	0.2	0.3	67.7
71119	point/mineral in SI	s1		0.4	0.1	28.8	1.4		0.1	1.1	0.1	0.4	67.4
71119	point/mineral in SI	s1	0.2	0.2	1.0	23.8	6.0		0.3	1.0		0.3	67.1
71119	point/mineral in SI	s1		0.4	0.2	28.9	1.9		0.1	2.3	0.1	0.3	65.7
71119	point/mineral in SI	s2	0.5	0.4	0.9	1.7	15.7	0.2	0.6	14.1	0.2	0.3	65.5
71119	point/mineral in SI	s2	0.2	0.8	0.7	27.4	4.4			1.0	0.2	0.5	64.9
71119	point/mineral in SI	s2	0.3	0.7	1.3	26.8	7.2		0.2	2.5	0.3	0.3	60.4
71119	point/mineral in SI	s4		1.4	1.9	12.6	15.2	1.6	0.4	7.1	0.3	0.8	58.7
71119	point/mineral in SI	s1	0.3	0.2	24.5	15.0	3.1		1.1	0.3	0.4	0.3	54.7
71119	point/mineral in SI	s4	0.4	1.2	2.5	16.4	16.2	1.0	0.6	8.1	0.3	0.8	52.4

Table G.1 (Continued)

71119	point/mineral in SI	s2	1.0	0.4	0.5	2.1	29.9		1.0	30.5	0.2	0.2	34.2
71121	point/mineral in SI	s3		0.1	0.7	0.6	0.1	0.2	0.1	0.2	0.2	0.4	97.4
71121	point/mineral in SI	s2	0.2	0.3	0.7	0.5	0.2	0.2	0.1	0.3	0.2	0.2	97.3
71121	point/mineral in SI	s3		0.3	0.3	0.6	0.5	0.6	0.2	0.3	0.2	0.3	96.7
71121	point/mineral in SI	s1		0.2	0.9	0.7	0.5	0.4		0.2	0.3	0.4	96.5
71121	point/mineral in SI	s4	0.3	0.2		1.1	0.8	0.5		0.3		0.3	96.4
71121	point/mineral in SI	s3	0.5	0.8	0.6	0.8	0.6	0.5	0.1			0.2	95.7
71121	point/mineral in SI	s1		0.2	1.0	1.0	0.6	0.3	0.1	0.4	0.3	0.4	95.6
71121	point/mineral in SI	s4	0.3	0.4	0.7	1.2	1.6	0.2		0.6	0.2	0.3	94.5
71121	point/mineral in SI	s2		0.2	0.9	1.9	1.1	0.2	0.2	0.6	0.2	0.3	94.4
71121	point/mineral in SI	s3	0.2	0.3	1.0	1.3	1.6		0.1	0.5	0.2	0.2	94.4
71121	point/mineral in SI	s2	0.2	0.3	0.8	1.6	2.0		0.1	0.8	0.2	0.3	93.7
71121	point/mineral in SI	s1		0.3	1.1	1.7	1.6	0.3	0.1	0.8	0.2	0.4	93.5
71121	point/mineral in SI	s1		0.5	0.9	2.4	2.1	0.2	0.2	0.6	0.3	0.6	92.3
71121	point/mineral in SI	s4	0.6	0.3	0.2	2.2	2.7	0.5	0.2	0.9	0.2	0.4	91.9
71121	point/mineral in SI	s2		0.4	0.8	2.2	3.3			1.6	0.2	0.3	91.2
71121	point/mineral in SI	s4	0.5	0.5	1.1	3.1	3.5		0.1	0.9	0.3	0.4	89.4
71121	point/mineral in SI	s3		0.4	0.7	3.2	8.1	0.2	0.3	2.5	0.2	0.5	83.9
71121	point/mineral in SI	s4	0.4	0.6	0.4	6.2	10.8	0.3	0.1	2.5	0.2	0.7	77.7
71121	point/mineral in SI	s4	0.4	0.5	0.9	5.9	10.5	0.1	0.4	3.2	0.2	0.4	77.4
71121	point/mineral in SI	s1	0.2	0.5	1.5	8.6	9.3	0.5	0.6	3.4	0.1	0.6	74.6
71121	point/mineral in SI	s4	0.4	0.6	1.6	8.0	16.8	1.6	0.7	5.3	0.2	0.6	64.2
71121	point/mineral in SI	s1	0.2	0.6	2.1	11.6	12.8	1.4	1.1	5.1	0.3	0.6	64.2
71121	point/mineral in SI	s4	0.3	0.8	1.1		20.3	0.4	0.6	6.9		0.7	58.6
71121	point/mineral in SI	s1	0.4	0.7	0.4	10.3	21.2	0.2	0.3	7.5	0.3	0.7	58.0
71121	point/mineral in SI	s1	0.4	0.9	0.6	12.6	20.1	0.2	0.2	6.4	0.2	0.7	57.8
71121	point/mineral in SI	s1	0.3	1.0	0.3	13.0	22.0	0.1	0.3	7.4	0.2	0.7	54.7
71121	point/mineral in SI	s3	0.2	0.7	0.4	8.4	25.2	0.3	0.5	9.1	0.2	0.6	54.3
71121	point/mineral in SI	s3	0.2	1.2	0.3	10.5	28.2		0.2	6.2		0.6	52.5

Table G.1 (Continued)

71121	point/mineral in SI	s1	0.2	0.7	0.5	14.7	22.9		0.3	7.7		0.6	52.3
71121	point/mineral in SI	s4	0.3	0.8	0.6	11.1	24.5		0.5	9.6	0.2	0.6	51.6
71121	point/mineral in SI	s3		1.1	0.3	9.2	30.7		0.1	8.5	0.2	0.5	49.4
71121	point/mineral in SI	s4	0.3	0.8	0.6	11.1	26.5	0.2	0.4	1	0.2	0.6	49.3
71121	point/mineral in SI	s2	0.2	0.9	1.1	13.7	26.0		0.9	10.9	0.2	0.5	45.6
71121	point/mineral in SI	s2	0.3	0.9	0.9	11.5	25.7		1.1	13.8		0.4	45.4
71121	point/mineral in SI	s2	0.2	0.9	1.0	13.1	26.5		1.0	11.9	0.1	0.5	44.7
71121	point/mineral in SI	s2	0.2	0.8	1.2	14.0	26.2		1.1	11.3	0.1	0.4	44.6
71121	point/mineral in SI	s2	0.4	0.9	1.3	13.8	25.7	0.1	1.1	11.3	0.2	0.6	44.6
71121	point/mineral in SI	s2	0.1	0.9	1.0	11.2	28.1	0.2	1.0	15.6	0.1	0.5	41.1
71126	point/mineral in SI	s6(upper)		0.1		0.3	0.3	0.4	0.1	0.1		0.3	98.3
71126	point/mineral in SI	s6(upper)		0.2		0.3	0.1	0.3		0.1	0.2	0.3	98.3
71126	point/mineral in SI	s6(upper)	0.1	0.3	0.2	0.3	0.1			0.1	0.1	0.3	98.3
71126	point/mineral in SI	s5(upper)		0.2		0.3	0.3	0.2	0.1	0.1	0.1	0.3	98.2
71126	point/mineral in SI	s3(lower)	0.2			0.3	0.2	0.2	0.1	0.2	0.1	0.3	98.2
71126	point/mineral in SI	s6(upper)		0.2		0.3	0.3	0.3			0.1	0.2	98.2
71126	point/mineral in SI	s2(lower)		0.2	0.2	0.4	0.2	0.3		0.1	0.1	0.3	97.9
71126	point/mineral in SI	s5(upper)	0.1	0.2	0.2	0.5	0.5	0.3	0.1	0.1		0.3	97.7
71126	point/mineral in SI	s6(upper)		0.2	0.1	0.7	0.6	0.3		0.3		0.2	97.5
71126	point/mineral in SI	s3(lower)		0.3	0.3	0.8	0.4	0.3	0.1	0.5	0.2	0.3	96.8
71126	point/mineral in SI	s1(lower)	0.2	0.5	0.3	0.6	0.5	0.6	0.2	0.2	0.1	0.3	96.5
71126	point/mineral in SI	s6(upper)		0.3	0.3	0.5	0.6	0.6	0.3	0.3	0.3	0.4	96.5
71126	point/mineral in SI	s2(lower)	0.5	0.5	0.6	1.2	0.5	0.3	0.1	0.3		0.3	95.7
71126	point/mineral in SI	s1(lower)	0.6	0.7	0.7	0.8	0.4	0.4	0.2	0.2	0.2	0.3	95.6
71126	point/mineral in SI	s2(lower)		0.4	0.4	0.7	0.7	0.8	0.4	0.4	0.5	0.6	95.0
71126	point/mineral in SI	s6(upper)	0.2	0.5	0.7	1.2	1.7	0.8	0.3	0.6	0.3	0.5	93.4
71126	point/mineral in SI	s4(upper)	0.2	0.3	0.5	1.5	2.7	1.1		0.5	0.2	0.4	92.6
71126	point/mineral in SI	s4(upper)			0.7	2.1	2.8	0.8		0.5	0.3	0.6	92.1
71126	point/mineral in SI	s5(upper)				2.5	2.9	0.3	0.2	1.0	0.3	0.7	92.0

Table G.1 (Continued)

71126	point/mineral in SI	s5(upper)		0.5	0.5	2.2	2.5	0.9	0.4	0.9	0.5	0.7	90.9
71126	point/mineral in SI	s1(lower)	0.3	0.6	0.9	3.3	1.2	0.8	0.5	1.1	0.3	0.4	90.6
71126	point/mineral in SI	s5(upper)	0.4	0.7	0.8	3.4	2.2	0.8	0.3	0.7	0.2	0.6	89.7
71126	point/mineral in SI	s3(lower)	0.1	0.4	1.2	4.4	1.4	1.1	0.3	1.3		0.2	89.4
71126	point/mineral in SI	s2(lower)	0.5	0.8	1.2	3.6	2.6	0.6	0.1	1.6	0.2	0.2	88.4
71126	point/mineral in SI	s3(lower)	0.7	1.1	1.3	2.4	1.7	1.3	0.6	1.2	0.7	0.6	88.4
71126	point/mineral in SI	s3(lower)	0.2	0.5	1.1	3.4	2.9	1.0	0.3	2.0	0.1	0.3	88.1
71126	point/mineral in SI	s6(upper)		0.3	0.6	1.9	5.0	0.8	0.4	2.0	0.4	0.7	87.8
71126	point/mineral in SI	s2(lower)	0.3	0.8	1.3	9.6	1.9	0.5	0.2	1.2	0.2	0.4	83.6
71126	point/mineral in SI	s3(lower)	0.2	0.7	1.8	6.3	4.2	0.3	0.3	3.8		0.4	82.0
71126	point/mineral in SI	s1(lower)		0.5	1.4	10.7	2.0	0.4	0.4	2.2	0.3	0.5	81.6
71126	point/mineral in SI	s5(upper)	0.3	0.6	0.5	11.6	3.4	0.4		0.5	0.1	1.4	81.0
71126	point/mineral in SI	s4(upper)		0.6	0.4	2.8	11.5	1.5		2.9		0.8	79.3
71126	point/mineral in SI	s3(lower)	0.1	0.7	3.1	17.4	3.2	2.6	0.6	3.5	0.3	0.5	67.9
71126	point/mineral in SI	s1(lower)	0.4	1.1	2.3	13.4	8.3	0.9	0.6	6.2	0.4	0.5	66.0
71126	point/mineral in SI	s2(lower)	0.5	1.2	1.9	10.6	1	1.2	0.6	8.0	0.2	0.3	65.5
71126	point/mineral in SI	s4(upper)		0.7		9.8	16.1	1.5	0.2	4.8	0.3	1.8	64.7
71126	point/mineral in SI	s4(upper)	0.2	1.1	0.2	11.1	19.7	1.4	0.1	3.4	0.1	1.4	61.3
71126	point/mineral in SI	s5(upper)	0.2	0.4	0.1	23.9	10.2	0.2	0.2	1.7	0.3	2.6	60.2
71126	point/mineral in SI	s5(upper)		0.5	0.3	21.3	14.3	0.4	0.2	3.0	0.2	2.7	57.1
71126	point/mineral in SI	s4(upper)		0.9	0.3	4.0	30.1	0.8		8.8	0.2	1.9	52.9
71126	point/mineral in SI	s1(lower)	0.3	1.2	3.1		14.6		0.9	11.1	0.3	0.3	48.2
71126	point/mineral in SI	s3(lower)	1.0	1.5	2.5	10.8	19.1	1.0	0.6	16.8	0.2	0.3	46.2
71304	point/mineral in SI	s1	0.3	0.2	0.7	0.3	0.1		0.1	0.2	0.2	0.3	97.7
71304	point/mineral in SI	s1	0.1	0.1	0.6	0.4		0.2	0.2	0.2	0.3	0.3	97.6
71304	point/mineral in SI	s3			0.5	0.7	0.1	0.1	0.1	0.2	0.3	0.4	97.5
71304	point/mineral in SI	s3	0.2	0.3	0.5	0.6	0.1	0.1			0.2	0.5	97.3
71304	point/mineral in SI	s1	0.2	0.2	0.7	0.6			0.1	0.3	0.2	0.4	97.2
71304	point/mineral in SI	s1			0.7	0.7	0.3	0.3		0.2	0.2	0.4	97.1

Table G.1 (Continued)

71304	point/mineral in SI	s1	0.3	0.3	0.4	0.5	0.3	0.2	0.2	0.2	0.2	0.4	97.0
71304	point/mineral in SI	s1	0.2	0.2	0.6	0.5	0.2	0.2	0.2	0.2	0.2	0.4	97.0
71304	point/mineral in SI	s3	0.7	0.8	1.0	1.9	1.3	0.3	0.2	0.8	0.1	0.5	92.5
71304	point/mineral in SI	s3	0.9	1.0	1.2	1.9	1.6	0.9	0.3	0.7		0.5	91.0
71304	point/mineral in SI	s3		0.3	1.1	4.7	4.5		0.1	2.5	0.2	0.5	86.1
71304	point/mineral in SI	s3	0.4	0.5	0.9	5.9	5.8	0.1	0.3	3.3	0.3	0.5	81.9
71304	point/mineral in SI	s1	0.2	0.7	0.7	7.7	7.1		0.3	1.6	0.2	0.4	80.9
71304	point/mineral in SI	s1	0.2	0.5	0.7	8.7	7.8	0.1	0.3	1.6	0.2	0.5	79.4
71304	point/mineral in SI	s2	0.1	0.2	0.2	13.1	6.7	0.2	0.2	0.7	0.3	3.7	74.6
71304	point/mineral in SI	s2	0.2	0.2	0.2	14.7	5.6	0.2	0.1	0.5	0.3	3.8	74.1
71304	point/mineral in SI	s3	0.2	0.5	1.3	9.6	8.6	0.3	0.3	4.8	0.2	0.5	73.8
71304	point/mineral in SI	s3	0.2	0.6	1.3	10.2	8.6	0.3	0.3	4.2	0.3	0.6	73.3
71304	point/mineral in SI	s1	0.3	0.9	1.1	9.7	11.0	0.2	0.5	4.1	0.1	0.3	71.9
71304	point/mineral in SI	s1	0.6	0.8	1.2	9.9	12.9		0.7	5.7		0.4	67.8
71304	point/mineral in SI	s6	1.2	1.7	2.6	9.8	7.3	1.5	1.0	5.3	1.8	1.4	66.4
71304	point/mineral in SI	s6	1.1	1.8	2.7	11.1	8.3	1.5	1.1	6.1	1.8	1.6	63.0
71304	point/mineral in SI	s2				19.2	13.0			0.3	0.4	4.3	62.8
71304	point/mineral in SI	s2	0.1	0.2	0.1	18.9	13.3	0.1	0.1	0.3	0.1	4.3	62.5
71304	point/mineral in SI	s5	0.8	0.6	3.0	19.7	5.6		1.3	4.5	0.6	2.5	61.5
71304	point/mineral in SI	s2	0.2	0.1	0.1	26.0	7.0		0.3	0.8	0.3	4.2	61.0
71304	point/mineral in SI	s5	0.7	0.9	2.9	19.8	6.1	0.3	1.3	4.2	0.6	2.3	60.9
71304	point/mineral in SI	s2		0.2		25.7	7.9	0.1	0.2	0.8	0.2	4.1	60.7
71304	point/mineral in SI	s4	0.3	2.1	5.4	16.1	2.8		0.8	5.3	4.7	4.1	58.5
71304	point/mineral in SI	s4	0.4	2.3	5.6	16.5	2.3	0.2	0.7	5.0	4.6	4.0	58.5
71304	point/mineral in SI	s6	0.1	0.6	2.5	17.7	9.8	0.3	1.0	8.1	0.6	1.6	57.6
71304	point/mineral in SI	s4	0.2	0.9	3.0	20.3	3.4	0.2	1.1	10.9	0.7	2.0	57.3
71304	point/mineral in SI	s6		0.6	2.7	18.1	9.7	0.5	1.2	8.1	0.5	1.3	57.2
71304	point/mineral in SI	s3	0.1	0.6	1.8	15.8	15.6		0.6	8.4	0.3	0.6	56.3
71304	point/mineral in SI	s3	0.3	0.7	1.8	14.8	15.6	0.3	0.7	9.3		0.4	56.0

Table G.1 (Continued)													
71304	point/mineral in SI	s4	0.3	1.2	3.3	20.9	3.3		1.1	11.1	0.7	2.0	55.9
71304	point/mineral in SI	s5	0.8	0.4	4.4	25.2	5.1	0.2	1.5	4.1	0.4	2.0	55.8
71304	point/mineral in SI	s5	0.9	0.5	7.0	25.5	2.5		1.4	2.1	3.5	1.8	54.7
71304	point/mineral in SI	s5	0.8	0.8	7.3	26.0	2.6	0.2	1.3	2.0	3.3	1.5	54.3
71304	point/mineral in SI	s5	0.8	0.3	5.2	27.9	4.4	0.3	1.7	4.1	0.6	1.9	52.7
71304	point/mineral in SI	s5	1.1	0.3	6.5	31.8	1.9		2.4	2.1	0.6	1.3	52.0
71304	point/mineral in SI	s1	1.2	0.9	0.4	4.0	23.4	0.1	0.6	17.5		0.2	51.6
71304	point/mineral in SI	s5	1.2	0.3	6.5	32.3	2.0		2.5	2.1	0.5	1.2	51.3
71304	point/mineral in SI	s1	1.0	0.8	0.3	3.7	24.2	0.1	0.6	18.0		0.3	51.0
71304	point/mineral in SI	s1	0.3	1.0	0.8	11.6	22.5		0.6	12.8	0.2	0.4	49.9
71304	point/mineral in SI	s7	0.6	1.3	4.1	27.2	3.0		1.4	9.4	0.8	2.5	49.6
71304	point/mineral in SI	s4	0.5	1.8	4.3	26.5	2.3		1.1	11.1	0.7	2.5	49.1
71304	point/mineral in SI	s7	0.5	1.4	4.1	27.2	3.1		1.3	9.7	0.8	2.8	49.0
71304	point/mineral in SI	s4	0.4	1.7	4.2	26.3	2.8		1.1	11.9	0.6	2.4	48.5
71304	point/mineral in SI	s5	0.9	0.8	5.6	34.2	4.8		1.9	2.4	0.4	1.9	47.1
71304	point/mineral in SI	s1	0.4	1.0	1.2	11.2	23.5		0.8	14.4	0.1	0.4	47.0
71304	point/mineral in SI	s5	1.0	0.9	5.6	35.1	4.7		1.9	2.4	0.4	1.9	45.9
71304	point/mineral in SI	s6	0.3	1.3	3.0	21.1	14.8	0.4	0.6	11.0	0.5	1.8	45.2
71304	point/mineral in SI	s6	0.4	1.2	3.1	21.4	14.7	0.5	0.7	10.8	0.5	1.7	44.9
71304	point/mineral in SI	s7	0.5	1.8	4.8	27.5	3.1		1.3	12.1	2.2	4.0	42.7
71304	point/mineral in SI	s7	0.4	1.7	4.5	28.1	3.2		1.3	12.5	2.3	4.1	41.9
71304	point/mineral in SI	s6	0.3	1.1	3.5	25.1	14.9	0.4	0.8	11.3	0.6	1.8	40.1
71304	point/mineral in SI	s6	0.3	1.2	3.6	24.7	15.2	0.6	0.7	11.5	0.5	1.7	39.9
71304	point/mineral in SI	s5	0.9	0.7	6.6	38.9	5.6		2.0	4.8	0.7	2.3	37.6
71304	point/mineral in SI	s5	0.9	0.8	6.7	39.0	5.5		2.0	4.8	0.7	2.3	37.4
71304	point/mineral in SI	s6	0.3	1.0	4.9	31.7	11.8		1.8	9.9	0.4	1.4	36.9
71304	point/mineral in SI	s6	0.5	0.8	5.1	32.3	11.5	0.3	1.9	9.2	0.5	1.5	36.4
71304	point/mineral in SI	s7	0.4	2.2	6.1	34.0	2.8		1.2	11.4	2.6	4.3	35.2
71304	point/mineral in SI	s7	0.5	2.2	5.9	33.9	2.8		1.2	11.3	2.7	4.5	35.0

Table G.1 (Continued)

71304	point/mineral in SI	s4	0.6	1.6	4.7	34.0	3.5		1.6	15.3	0.9	3.3	34.4
71304	point/mineral in SI	s4	0.5	2.4	4.7	29.3	6.3		1.2	16.3	1.7	3.6	33.9
71304	point/mineral in SI	s4	0.5	1.7	5.2	35.0	3.4		1.6	15.2	0.9	3.5	33.1
71304	point/mineral in SI	s4	0.5	2.3	4.7	30.7	6.7		1.3	16.6	1.8	3.7	31.8
71304	point/mineral in SI	s4	0.4	1.9	5.9	40.6	3.3		1.4	16.6	1.3	3.7	25.0
71304	point/mineral in SI	s4	0.5	2.0	6.1	40.8	3.6		1.4	16.5	1.1	3.5	24.5
71304	point/mineral in SI	s7	0.5	2.0	6.3	43.6	3.7		1.5	14.4	1.1	3.8	23.0
71304	point/mineral in SI	s7	0.5	2.1	6.5	43.7	4.0		1.5	14.3	1.1	3.7	22.7
71309	point/mineral in SI	s15			0.6	0.8	0.1	0.1		0.4	0.3	0.9	96.6
71309	point/mineral in SI	s15		0.3	0.5	0.8	0.4	0.3	0.1	0.4	0.3	0.8	96.1
71309	point/mineral in SI	s13		1.0	0.7	0.5		0.3			0.2	1.7	95.4
71309	point/mineral in SI	s1		0.8	0.9	0.6	0.2	0.2		0.1	0.3	1.6	95.2
71309	point/mineral in SI	s1		0.9	0.8	0.7		0.3	0.2	0.2	0.4	1.6	95.0
71309	point/mineral in SI	s1	0.1	0.8	0.8	0.4		0.2	0.1	0.2	0.4	2.0	94.9
71309	point/mineral in SI	s1	0.1	0.8	1.0	0.6	0.2		0.2	0.1	0.2	1.8	94.8
71309	point/mineral in SI	s13		1.1	0.9	0.6	0.2	0.3		0.2	0.4	1.6	94.8
71309	point/mineral in SI	s5		1.6	0.1	31.6	0.7			1.9		0.4	63.4
71309	point/mineral in SI	s5		2.0	0.4	31.7	0.4		0.1	1.9	0.2	0.5	63.0
71309	point/mineral in SI	s1	0.1	3.7	0.2	15.4	9.0		0.2	6.1	0.2	2.5	62.7
71309	point/mineral in SI	s1	1.3	0.6	5.9	10.4	8.0		3.9	5.3	0.2	1.7	62.5
71309	point/mineral in SI	s1	0.2	3.4		15.8	9.3	0.2	0.2	5.9	0.1	2.4	62.4
71309	point/mineral in SI	s1	1.4	0.6	6.4	10.9	7.6		4.0	5.0	0.2	1.8	62.1
71309	point/mineral in SI	s5	0.2	1.8	1.2	31.0	1.1	0.1	0.4	3.1	0.2	0.4	60.5
71309	point/mineral in SI	s5		2.0	1.3	31.1	0.8		0.4	3.2	0.2	0.5	60.4
71309	point/mineral in SI	s6		6.0		32.9	0.4		0.1	1.3	0.2	0.4	58.8
71309	point/mineral in SI	s6		6.0	0.2	32.8	0.8		0.2	1.3	0.2	0.6	57.9
71309	point/mineral in SI	s13	0.2	3.3	2.2	14.8	10.7	0.2	0.2	7.1	0.3	3.8	57.3
71309	point/mineral in SI	s13	0.1	3.2	2.2	15.0	11.1	0.2	0.1	7.1	0.3	3.6	57.1
71309	point/mineral in SI	s13	0.3	0.6	0.8	6.3	8.8		0.2	23.1	0.2	3.1	56.6

Table G.1 (Continued)

71309	point/mineral in SI	s15	0.3	1.3	0.8	22.8	13.3		0.3	3.1		2.3	55.8
71309	point/mineral in SI	s13		0.6	0.8	6.5	9.0	0.1	0.3	22.9	0.7	3.3	55.8
71309	point/mineral in SI	s15	0.1	1.4	0.9	22.6	13.4		0.3	3.3	0.2	2.3	55.6
71309	point/mineral in SI	s15	0.1	0.8	2.1	22.6	11.3		0.7	5.3	0.2	1.9	55.0
71309	point/mineral in SI	s15	0.2	0.9	2.1	22.5	11.0		0.7	5.5	0.2	2.0	54.9
71309	point/mineral in SI	s6	0.5	2.8	3.3	33.3	1.0		1.1	3.4	0.3	0.4	54.0
71309	point/mineral in SI	s6	0.6	2.9	3.8	33.6	1.1		1.0	3.4	0.3	0.5	52.7
71309	point/mineral in SI	s15	0.4	0.8	2.7	23.0	12.0	0.3	1.0	6.8	0.2	2.0	50.9
71309	point/mineral in SI	s15	0.1	0.8	2.9	23.4	12.1	0.2	0.9	6.8	0.1	2.0	50.7
71309	point/mineral in SI	s1		4.2	0.9	22.9	12.8		0.4	7.1		3.5	48.3
71309	point/mineral in SI	s1	0.2	4.2	1.1	23.0	12.7	0.2	0.5	7.2	0.2	3.7	47.1
71309	point/mineral in SI	s14		7.9	0.5	32.0	2.3		0.6	5.2	0.2	6.4	44.8
71309	point/mineral in SI	s14		7.8	0.7	31.9	2.3		0.7	5.4	0.1	6.4	44.7
71309	point/mineral in SI	s14		7.5	1.2	34.5	1.8		0.5	3.7	0.2	6.4	44.0
71309	point/mineral in SI	s14		7.6	1.4	34.4	2.0	0.1	0.4	3.7	0.2	6.4	43.7
71309	point/mineral in SI	s14	0.3	1.4	5.5	27.5	5.0		1.3	13.4	0.5	2.9	42.2
71309	point/mineral in SI	s14	0.4	1.6	5.6	28.0	4.9		1.4	13.5	0.4	2.7	41.3
71309	point/mineral in SI	s3	0.4	2.0	3.5	32.3	7.0		1.9	9.6	0.4	3.6	39.3
71309	point/mineral in SI	s3	0.4	1.9	3.6	32.5	6.8		2.0	9.7	0.2	3.6	39.3
71309	point/mineral in SI	s3	0.3	1.3	4.9	35.8	3.8		2.0	9.7	0.4	3.4	38.3
71309	point/mineral in SI	s3	0.4	1.4	5.3	36.0	4.0	0.1	2.0	9.7	0.5	3.5	37.1
71309	point/mineral in SI	s10	1.0	1.8	8.7	39.0	1.6		1.5	8.4	0.7	0.4	36.8
71309	point/mineral in SI	s14	0.4	1.4	5.5	3	5.6		1.5	16.1	0.5	3.6	35.5
71309	point/mineral in SI	s14	0.4	1.5	5.5	30.1	5.5	0.2	1.5	15.8	0.6	3.6	35.4
71309	point/mineral in SI	s3	0.3	0.8	5.2	35.3	5.7		2.0	14.2	0.6	2.9	32.9
71309	point/mineral in SI	s3	0.3	0.7	5.6	35.3	5.5		2.1	14.1	0.4	3.0	32.8
71309	point/mineral in SI	s3	0.6	0.6	5.4	30.7	9.6		1.6	18.4	0.6	1.9	30.5
71309	point/mineral in SI	s10	0.9	1.8	9.6	44.3	2.0	0.3	1.5	8.5	0.6	0.3	30.2
71309	point/mineral in SI	s10	0.9	2.0	9.6	44.6	1.6	0.1	1.4	8.6	0.6	0.4	30.1

Table G.1 (Continued)

71309	point/mineral in SI	s5	1.2	0.2	12.9	33.7	3.9	0.5	2.3	15.0	0.5		29.9
71309	point/mineral in SI	s5	1.2	0.2	12.9	34.0	3.7	0.3	2.2	15.1	0.5	0.2	29.8
71309	point/mineral in SI	s3	0.6	0.7	5.5	30.6	9.9		1.7	19.0	0.6	1.8	29.7
71309	point/mineral in SI	s9	1.3	2.1	10.3	45.5		0.2	2.4	9.5	0.7	0.4	27.6
71309	point/mineral in SI	s3	0.4	1.5	1.7	15.8	23.4	0.1	1.4	26.7	0.4	2.4	25.9
71309	point/mineral in SI	s3	0.6	1.6	2.0	15.9	23.1	0.2	1.4	26.4	0.4	2.5	25.8
71309	point/mineral in SI	s5	1.5	0.3	15.2	32.9	4.7	0.3	2.9	15.5	0.6	0.3	25.7
71309	point/mineral in SI	s5	1.5	0.1	15.2	33.2	4.4	0.2	3.1	15.6	0.8	0.2	25.6
71309	point/mineral in SI	s6	1.1	0.3	12.1	41.1	1.7	0.2	1.9	15.2	0.8	0.3	25.3
71309	point/mineral in SI	s6	1.1	0.4	12.1	41.0	2.0	0.2	2.1	15.1	0.9	0.3	24.9
71309	point/mineral in SI	s4	0.1	4.1	7.2	34.2	6.1		0.3	30.2	0.4	0.5	17.0
71309	point/mineral in SI	s4		4.2	7.2	34.1	6.2		0.6		0.5	0.4	16.9
71309	point/mineral in SI	s4		3.7	6.5	31.4	7.8		0.6	34.8	0.7	0.5	14.0
71309	point/mineral in SI	s4		3.9	6.3	31.3	7.9		0.6	34.8	0.8	0.4	14.0
71309	point/mineral in SI	s9	1.1	2.3	11.6	56.3	0.1	0.4	3.2	14.0	0.9	0.3	9.8
71309	point/mineral in SI	s9	1.2	2.2	11.8	56.7			3.2	14.1	0.8	0.3	9.7
71309	point/mineral in SI	s2	0.2	3.1	5.9	37.9	7.3		1.5	28.6	0.5	5.5	9.6
71309	point/mineral in SI	s2	0.2	3.1	5.7	37.4	7.3		1.8	29.0	0.7	5.4	9.4
71309	point/mineral in SI	s2	0.2	3.4	6.8	41.6	4.2		2.0	26.5	0.8	6.2	8.4
71309	point/mineral in SI	s2	0.2	3.5	6.6	41.7	4.1		2.0	26.8	0.7	6.2	8.1
71309	point/mineral in SI	s11	1.2	2.2	11.5	57.7	0.1	0.2	2.7	15.3	0.7	0.4	8.0
71309	point/mineral in SI	s11	1.1	2.2	11.7	58.1		0.3	2.7	15.3	0.7	0.2	7.7
71309	point/mineral in SI	s7	1.2	1.3	13.7	57.9		0.2	3.3	14.6	0.9	0.2	6.8
71309	point/mineral in SI	s7	1.2	1.4	13.9	57.5		0.3	3.3	14.8	0.9	0.1	6.6
71309	point/mineral in SI	s12		3.5	8.5	40.3	1.1	0.2	0.5	38.6	0.7	0.3	6.4
71309	point/mineral in SI	s12		3.4	8.5	40.3	0.9	0.2	0.6	38.7	1.0	0.2	6.2
71309	point/mineral in SI	s8	1.3	1.0	13.2	57.0		0.3	4.3	16.8	0.9	0.2	5.0
71309	point/mineral in SI	s8	1.3	1.0	13.2	57.3	0.2	0.4	4.2	16.9	0.6		5.0
71309	point/mineral in SI	s8	1.1	0.8	9.1	52.1	0.3	0.3	2.2	29.2	0.6	0.2	4.4

Table G.1 (Continued)

71309	point/mineral in SI	s8	1.0	0.8	9.1	52.4	0.2		2.1	29.3	0.4	0.1	4.3
71309	point/mineral in SI	s12		3.9	9.0	41.9	1.0		0.5	38.8	0.8	0.4	3.5
71309	point/mineral in SI	s7	1.1	1.5	12.1	57.5	0.2	0.4	2.9	19.8	0.9	0.1	3.3
71309	point/mineral in SI	s7	1.2	1.7	12.3	57.4	0.3	0.4	3.1	19.4	0.9	0.2	3.1
71309	point/mineral in SI	s11	1.1	2.0	12.0	61.3		0.1	3.0	16.8	0.8	0.4	2.4
71312	point/mineral in SI	s2		0.3	0.4	0.3	0.2	0.3		0.4	0.2	0.4	97.5
71312	point/mineral in SI	s4		0.5	0.3	0.3	0.1	0.2	0.1	0.4	0.3	0.2	97.5
71312	point/mineral in SI	s1		0.4	0.3	0.3		0.2	0.1	0.4	0.2	0.5	97.4
71312	point/mineral in SI	s1		0.4	0.4	0.5	0.1	0.2	0.1	0.4	0.1	0.4	97.4
71312	point/mineral in SI	s1		0.4	0.3	0.7		0.2	0.1	0.4	0.2	0.3	97.4
71312	point/mineral in SI	s4			0.3	0.9	0.3	0.3		0.3		0.4	97.3
71312	point/mineral in SI	s2	0.1	0.2	0.4	0.2		0.3	0.2	0.5	0.2	0.5	97.3
71312	point/mineral in SI	s2	0.1	0.5	0.3	0.4	0.2	0.3		0.4	0.2	0.4	97.3
71312	point/mineral in SI	s3		0.6	0.4	0.5		0.1		0.2	0.1	0.4	97.2
71312	point/mineral in SI	s3	0.2	0.7	0.3	0.5	0.1	0.2		0.2	0.1	0.4	97.2
71312	point/mineral in SI	s4	0.2	0.4	0.4	0.5		0.2	0.1	0.4	0.2	0.3	97.2
71312	point/mineral in SI	s1	0.1	0.3	0.3	0.7	0.5	0.4		0.3		0.4	96.9
71312	point/mineral in SI	s1		0.2	0.3	0.7	0.4	0.4	0.1	0.4	0.3	0.4	96.8
71312	point/mineral in SI	s3		0.6	0.3	0.9	0.1			0.6	0.2	0.4	96.8
71312	point/mineral in SI	s3	0.2	0.3	0.2	0.9	0.3	0.3		0.5	0.2	0.4	96.7
71312	point/mineral in SI	s1	0.2	0.7	0.5	0.4	0.2	0.3	0.1	0.3	0.2	0.5	96.7
71312	point/mineral in SI	s4		0.3	0.4	1.1	0.2	0.2	0.1	0.4		0.6	96.6
71312	point/mineral in SI	s2			0.2	0.7	0.3	0.4	0.2	1.0	0.2	0.4	96.3
71312	point/mineral in SI	s1	0.2	0.5	0.5	0.8	0.4	0.3	0.1	0.3	0.1	0.4	96.3
71312	point/mineral in SI	s2		0.4	0.5	0.4	0.3	0.5	0.2	0.7	0.4	0.5	96.2
71312	point/mineral in SI	s2		0.6	0.5	0.7	0.7	0.1	0.1	0.9	0.2	0.5	95.8
71312	point/mineral in SI	s2	0.5	0.4	0.3	0.7	0.2	0.2	0.1	1.1	0.2	0.6	95.7
71312	point/mineral in SI	s1	0.6	0.7	0.6	0.7	0.5	0.5		0.2	0.2	0.2	95.6
71312	point/mineral in SI	s2	0.3	0.3	0.3	1.3	0.2	0.1		1.3	0.1	0.4	95.6

Table G.1 (Continued)													
71312	point/mineral in SI	s1		0.6	0.4	1.4	0.4	0.2	0.1	1.2	0.2	0.5	95.0
71312	point/mineral in SI	s1	0.8	0.8	0.7	0.7	0.6	0.5	0.1	0.3	0.1	0.3	95.0
71312	point/mineral in SI	s2	0.4	0.3	0.4	1.7	0.2	0.2		1.3		0.4	94.9
71312	point/mineral in SI	s2		0.4	0.5	1.0	1.2	0.2	0.2	1.1	0.2	0.3	94.8
71312	point/mineral in SI	s1	0.9	0.9	0.7	0.9	0.8	0.5	0.1	0.4		0.4	94.5
71312	point/mineral in SI	s3		0.5	0.6	3.4	1.1	0.4		1.8	0.1	0.3	91.7
71312	point/mineral in SI	s3		0.5	0.7	3.9	1.4	0.6	0.2	2.3	0.2	0.4	89.7
71312	point/mineral in SI	s4	0.2	0.2		3.8	4.4	0.8		1.2	0.2	0.4	88.9
71312	point/mineral in SI	s4	0.3	0.3	0.2	4.1	4.5	0.6		1.1		0.5	88.4
71312	point/mineral in SI	s1	0.5	0.6	3.4	24.2	3.0	0.2	1.0	11.3	0.1	0.4	55.3
71312	point/mineral in SI	s1	0.6	0.7	3.4	24.1	3.1	0.3	1.1	11.3	0.2	0.5	54.7
71312	point/mineral in SI	s3	0.4	0.7	0.3	4.1	30.3	0.4	1.0	30.6	0.1	0.4	31.6
71312	point/mineral in SI	s3	0.2	0.4	1.0	12.5	24.0	2.4	0.4	29.5		0.2	29.4
71312	point/mineral in SI	s3	0.4	0.6	0.3	4.0	32.8	0.4	1.2	33.9		0.3	26.1
71312	point/mineral in SI	s3	0.3	0.5	1.5	11.4	25.3	3.2	0.6	30.8	0.2	0.3	25.9
71312	point/mineral in SI	s3	1.1	1.0	0.9	5.9	29.5	2.3	0.8	36.0	0.1	0.2	22.1
71312	point/mineral in SI	s3	0.7	0.9	0.7	4.6	33.4	0.7	1.2	35.5		0.2	22.0
71312	point/mineral in SI	s3	0.6	0.6	0.6	5.7	30.5	2.5	1.0	37.9	0.2	0.2	20.2
71312	point/mineral in SI	s3	0.3	0.3	0.1	4.2	34.4	0.5	1.4	39.6	0.3	0.2	18.6
71312	point/mineral in SI	s4	1.0	0.5	0.5	3.3	35.5		1.2	42.5	0.1	0.3	15.0
71312	point/mineral in SI	s4	0.8	0.6	0.6	3.3	35.7		1.2	42.6		0.2	14.9
71312	point/mineral in SI	s3	0.2	0.5	0.2	4.1	36.0	0.4	1.4	44.8		0.2	12.2
71312	point/mineral in SI	s3	0.3	0.4		4.1	35.8	0.4	1.5	45.2		0.2	12.1
71312	point/mineral in SI	s4	0.7	0.4	0.5	7.1	35.8		1.3	42.6		0.3	11.1
71312	point/mineral in SI	s4	0.6	0.5	0.6	7.2	36.3	0.2	1.2	42.7			10.6
71312	point/mineral in SI	s3	1.0	1.1	1.0	5.2	34.8	2.4	1.1	42.8		0.2	10.4
71312	point/mineral in SI	s3	1.0	1.1	1.1	5.0	35.3	2.1	1.1	43.5	0.1		9.7
71312	point/mineral in SI	s4	0.8	0.4	0.2	3.8	39.7		1.0	46.4		0.1	7.6
71312	point/mineral in SI	s4	0.7	0.4	0.2	3.6	39.6		1.2	46.5		0.3	7.4

Table G.1 (Continued)

71312	point/mineral in SI	s3	0.4	0.4		3.4	39.7		1.5	47.4		0.1	7.1
71312	point/mineral in SI	s3	0.4	0.4	0.2	3.1			1.5	47.2		0.3	6.9
71316	point/mineral in SI	s1	0.1	0.4	0.3	0.7	0.2	0.7	0.1	0.3	0.3	0.4	96.3
71316	point/mineral in SI	s16		0.2	0.8	0.8	0.1	0.3	0.1	0.3	0.6	1.1	95.7
71316	point/mineral in SI	s1	0.2	0.2	0.1	0.9	0.5	1.1	0.2	0.4	0.3	0.4	95.7
71316	point/mineral in SI	s16	0.3	0.2	1.1	0.7				0.2	0.6	1.1	95.5
71316	point/mineral in SI	s1	3.6	3.7	3.3	3.8	2.6	2.9	0.5	0.7		0.5	78.4
71316	point/mineral in SI	s1	3.7	3.8	3.4	3.9	2.4	2.8	0.4	0.7	0.2	0.2	78.4
71316	point/mineral in SI	s27	1.1	0.6	5.3	21.3	0.7	0.1	0.6	1.7	0.4	0.4	67.8
71316	point/mineral in SI	s27	0.8	0.5	5.1	21.8	0.8	0.2	0.7	1.6	0.4	0.5	67.6
71316	point/mineral in SI	s27	0.7	1.1	4.2	27.6	0.6		0.6	1.5	0.5	0.5	62.8
71316	point/mineral in SI	s27	0.8	0.9	4.1	27.7	0.8	0.2	0.6	1.5	0.4	0.5	62.5
71316	point/mineral in SI	s27	1.0	0.7	6.1	26.0	0.7	0.2	0.8	1.9	0.5	0.5	61.7
71316	point/mineral in SI	s27	1.1	0.4	6.2	26.5	0.7		0.8	2.0	0.4	0.4	61.6
71316	point/mineral in SI	s25	0.6	0.9	4.3	19.0	3.2		1.9	8.0	0.3	0.7	61.1
71316	point/mineral in SI	s27	0.8	0.7	5.1	28.2	0.6		0.7	2.0	0.4	0.6	60.9
71316	point/mineral in SI	s27	0.7	0.8	5.0	28.5	0.8	0.2	0.8	1.9	0.5	0.4	60.5
71316	point/mineral in SI	s25	0.6	1.1	4.4	18.7	3.5		2.0	8.3	0.4	0.5	60.5
71316	point/mineral in SI	s15		3.1	0.4	32.7	0.2		0.1	1.3	0.3	3.1	58.8
71316	point/mineral in SI	s15		3.1	0.2	33.1				1.2	0.3	3.2	58.7
71316	point/mineral in SI	s15		4.7	0.2	33.0				1.0	0.2	3.1	57.7
71316	point/mineral in SI	s1		3.4	0.3	32.6	0.4		0.2	1.3	0.4	3.9	57.4
71316	point/mineral in SI	s15		4.9	0.2	33.0		0.1	0.1	1.0	0.2	3.2	57.3
71316	point/mineral in SI	s16		5.0	0.8	32.2	0.4			1.1	0.2	2.8	57.3
71316	point/mineral in SI	s1	0.3	3.5	0.8	32.0	0.3		0.2	1.3	0.4	4.1	57.1
71316	point/mineral in SI	s16	0.1	4.8	1.0	32.4	0.3	0.1	0.1	1.1	0.3	2.8	57.0
71316	point/mineral in SI	s2	0.7	1.1	4.1	30.5	0.7	0.1	1.1	5.0	0.3	0.8	55.5
71316	point/mineral in SI	s2	0.5	1.1	3.7	32.5	0.7		1.0	4.8	0.4	0.9	54.4
71316	point/mineral in SI	s2	0.6	1.3	3.8	32.2	0.7	0.1	1.0	4.8	0.3	1.0	54.2

Table G.1 (Continued)

71316	point/mineral in SI	s25	0.3	2.2	3.3	26.4	2.5		1.8	8.5	0.5	0.7	53.8
71316	point/mineral in SI	s25	0.4	2.5	3.5	26.6	2.3		1.8	8.3	0.3	0.7	53.6
71316	point/mineral in SI	s25	0.5	2.0	3.2	25.3	3.3		1.8	9.6	0.5	0.8	52.8
71316	point/mineral in SI	s2	1.2	0.7	6.4	29.6	0.9		1.5	5.9	0.4	0.9	52.4
71316	point/mineral in SI	s25	0.6	2.0	3.3	25.4	3.3		1.8	9.8	0.5	0.9	52.4
71316	point/mineral in SI	s1		9.4	0.7	33.5	0.2	0.2	0.1	0.9	0.2	4.0	50.8
71316	point/mineral in SI	s1	0.2	9.3	1.2	33.1	0.1	0.2	0.2	0.8	0.3	3.9	50.7
71316	point/mineral in SI	s12	0.7	1.1	4.0	34.2	0.1	0.2	1.2	4.8	2.3	3.7	47.8
71316	point/mineral in SI	s12	0.6	1.2	4.1	34.2	0.2	0.3	1.1	4.6	2.3	3.6	47.8
71316	point/mineral in SI	s24	0.6	1.2	6.3	31.3	0.5		2.6	9.0	0.5	1.5	46.7
71316	point/mineral in SI	s24	0.7	1.2	6.5	30.9	0.4	0.1	2.7	9.0	0.6	1.4	46.5
71316	point/mineral in SI	s24	0.4	2.2	4.0	31.6	0.4		2.1	10.4	0.4	2.1	46.4
71316	point/mineral in SI	s2	1.1	0.8	7.0	34.4	0.9	0.1	1.7	6.8	0.4	0.7	46.1
71316	point/mineral in SI	s2	1.1	0.9	6.9	35.0	0.9		1.5	6.5	0.3	0.9	46.0
71316	point/mineral in SI	s24	0.7	1.0	6.5	29.9	0.6	0.2	2.8	10.2	0.5	1.6	45.9
71316	point/mineral in SI	s24	0.5	2.2	4.0	31.6	0.7	0.4	2.1	10.3	0.4	2.1	45.8
71316	point/mineral in SI	s24	0.6	0.9	6.5	29.9	0.7	0.3	2.9	10.3	0.7	1.6	45.6
71316	point/mineral in SI	s17	0.1	12.9	0.4	35.4	0.3	0.1		0.9	0.2	5.5	44.2
71316	point/mineral in SI	s17		12.8	0.6	35.6	0.2	0.2		0.8	0.1	5.4	44.1
71316	point/mineral in SI	s17		10.4	1.3	36.0	0.1		0.6	2.0	0.4	5.2	44.0
71316	point/mineral in SI	s17		10.9	1.4	35.3	0.4	0.1	0.7	2.0	0.5	5.2	43.4
71316	point/mineral in SI	s13	1.1	1.4	5.9	34.8		0.2	1.7	7.5	0.7	4.2	42.5
71316	point/mineral in SI	s13	1.1	1.6	6.1	34.6		0.3	1.8	7.4	0.7	4.4	41.9
71316	point/mineral in SI	s26	0.5	2.1	4.5	36.9	0.8		2.4	9.5	0.3	3.9	39.0
71316	point/mineral in SI	s21	0.9	2.5	7.5	40.6			1.1	6.0	0.5	1.9	38.8
71316	point/mineral in SI	s21	0.8	2.5	7.2	40.9	0.1	0.2	1.2	6.1	0.5	1.8	38.6
71316	point/mineral in SI	s26	0.5	2.5	4.5	36.6	1.2		2.5	9.3	0.5	3.8	38.6
71316	point/mineral in SI	s26	0.4	2.0	4.6	39.4	0.8		2.5	10.3	0.7	3.7	35.5
71316	point/mineral in SI	s26	0.7	2.2	4.8	39.3	0.9		2.5	10.5	0.6	3.5	35.0

Table G.1 (Continued)

71316	point/mineral in SI	s11			0.5	61.9		0.2		0.2	1.5	0.4	34.9
71316	point/mineral in SI	s13	1.2	1.7	6.9	39.4	0.1	0.2	1.9	8.6	0.7	4.7	34.7
71316	point/mineral in SI	s11			0.4	62.7		0.2	0.1	0.2	1.6	0.4	34.2
71316	point/mineral in SI	s1	2.1	0.8	12.9	39.0	0.8	0.1	2.0	5.8	0.8	2.3	33.3
71316	point/mineral in SI	s1	2.2	0.9	13.1	39.1	0.8	0.2	2.2	5.9	0.8	2.4	32.6
71316	point/mineral in SI	s10	1.3	2.5	9.5	43.5		0.2	1.3	6.9	1.0	2.0	31.7
71316	point/mineral in SI	s10	1.4	2.4	9.7	43.7	0.1	0.4	1.4	7.1	0.8	2.3	30.7
71316	point/mineral in SI	s26	0.9	0.9	6.7	41.1	1.8	0.2	3.8	13.6	0.8	2.7	27.5
71316	point/mineral in SI	s26	0.9	1.1	6.8	41.5	2.0		3.5	13.4	0.9	2.4	27.5
71316	point/mineral in SI	s15	1.9	0.2	16.9	37.0	1.7	0.3	3.3	11.5	1.2	0.9	25.0
71316	point/mineral in SI	s15	1.9	0.3	16.6	37.7	1.6	0.3	3.4	11.5	1.0	0.8	24.9
71316	point/mineral in SI	s1	2.1	0.3	14.7	41.6	1.0	0.1	2.8	9.7	1.0	1.8	24.9
71316	point/mineral in SI	s23	0.7	3.4	8.6	44.4	0.2	0.1	2.1	9.7	1.4	5.1	24.2
71316	point/mineral in SI	s1	2.1	0.5	14.9	41.8	1.0	0.3	2.8	9.8	0.9	1.7	24.2
71316	point/mineral in SI	s18	1.0	3.9	8.6	45.9		0.3	1.9	9.6	1.2	3.7	24.0
71316	point/mineral in SI	s23	1.0	3.6	8.4	44.5	0.1	0.1	2.1	9.6	1.6	5.1	24.0
71316	point/mineral in SI	s16	3.8		15.4	37.6	2.5	0.3	4.2	10.5	0.7	0.9	24.0
71316	point/mineral in SI	s17	1.6	1.2	12.7	44.8	0.5	0.2	2.3	8.7	1.6	2.8	23.6
71316	point/mineral in SI	s17	1.7	1.1	12.8	44.9	0.6		2.3	8.6	1.5	2.8	23.6
71316	point/mineral in SI	s16	3.5	0.2	15.7	37.9	2.4	0.4	4.4	10.5	0.7	0.9	23.5
71316	point/mineral in SI	s21	1.0	2.8	8.7	50.6		0.2	1.7	8.5	0.7	2.5	23.1
71316	point/mineral in SI	s20	0.8	3.0	9.1	48.6	0.3	0.3	2.3	12.5	0.7	0.6	21.8
71316	point/mineral in SI	s20	1.0	3.1	9.2	48.5	0.2	0.2	2.5	12.5	0.8	0.6	21.4
71316	point/mineral in SI	s5	0.9	1.6	9.2	53.8	0.1	0.2	2.0	8.5	0.6	1.7	21.3
71316	point/mineral in SI	s18	1.1	3.7	8.3	45.7	0.3	0.4	2.2	11.6	1.3	4.6	20.9
71316	point/mineral in SI	s5	1.1	1.6	9.2	53.9	0.2	0.4	2.1	8.5	0.6	1.8	20.6
71316	point/mineral in SI	s20	0.9	2.3	9.5	50.2	0.3	0.2	2.8	11.9	0.7	0.5	20.6
71316	point/mineral in SI	s18	1.1	3.8	8.4	45.7	0.2	0.2	2.2	11.7	1.5	4.8	20.4
71316	point/mineral in SI	s23	0.8	3.3	9.3	48.5	0.2	0.2	2.5	9.8	1.6	4.7	19.3

Table G.1 (Continued)

71316	point/mineral in SI	s17	1.4	0.6	13.1	47.0	0.7	0.1	2.1	12.6	1.6	2.4	18.6
71316	point/mineral in SI	s17	1.4	0.6	12.9	47.6	0.6	0.1	2.0	12.6	1.4	2.2	18.6
71316	point/mineral in SI	s6	1.7	2.2	9.1	51.0	0.2	0.2	3.3	11.5	1.4	1.2	18.1
71316	point/mineral in SI	s6	1.7	2.2	9.1	51.2	0.2	0.1	3.4	11.6	1.4	1.4	17.8
71316	point/mineral in SI	s22	1.5	2.5	10.5	53.6		0.1	2.9	12.1	0.8	0.8	15.3
71316	point/mineral in SI	s6	1.8	2.3	9.4	53.7		0.1	3.3	11.5	1.5	1.2	15.2
71316	point/mineral in SI	s5	1.2	1.8	9.4	56.8	0.1	0.2	2.2	10.2	0.8	2.1	15.1
71316	point/mineral in SI	s22	1.6	2.3	10.4	53.9		0.2	3.0	12.0	0.8	0.9	15.1
71316	point/mineral in SI	s12	0.8	1.6	6.1	56.4	0.2	0.6	2.0	8.7	4.3	6.0	13.3
71316	point/mineral in SI	s9	1.5	3.3	11.0	49.1	0.1	0.3	3.4	15.7	1.4	1.6	12.6
71316	point/mineral in SI	s9	1.4	3.1	11.8	53.4			3.1	14.6	1.0	1.1	10.4
71316	point/mineral in SI	s9	1.4	3.2	11.8	53.1	0.2	0.2	3.1	14.5	1.1	1.1	10.3
71316	point/mineral in SI	s14	1.6	2.8	12.7	51.2	0.1	0.3	4.0	15.7	0.9	0.9	9.7
71316	point/mineral in SI	s14	1.5	2.6	12.6	51.4	0.2	0.4	4.0	15.8	1.0	0.9	9.6
71316	point/mineral in SI	s19	1.0	3.7	9.3	57.1		0.2	1.9	11.0	1.1	5.1	9.4
71316	point/mineral in SI	s7	1.2	2.1	9.8	58.8	0.2	0.3	3.0	13.9	0.9	1.6	8.3
71316	point/mineral in SI	s19	0.9	4.3	9.8	57.2	0.2	0.1	2.4	11.2	1.1	4.7	8.1
71316	point/mineral in SI	s19	0.8	4.4	9.8	58.2			2.3	11.0	1.0	4.6	8.0
71316	point/mineral in SI	s7	1.3	2.1	9.8	59.0	0.2	0.3	3.0	13.9	0.9	1.6	8.0
71316	point/mineral in SI	s4	1.0	3.3	10.8	59.7	0.2	0.2	2.9	13.4	1.1	2.0	5.4
71316	point/mineral in SI	s4	1.2	3.3	10.8	59.4	0.1	0.2	2.9	13.4	1.3	2.1	5.3
71316	point/mineral in SI	s14	1.7	2.5	12.4	51.8			4.5	19.5	1.3	1.4	4.9
71316	point/mineral in SI	s3	1.3	3.2	11.4	56.8	0.2	0.2	3.4	15.3	1.6	1.7	4.9
71316	point/mineral in SI	s10	1.2	2.5	1	61.7		0.2	2.6	12.9	0.9	3.3	4.8
71316	point/mineral in SI	s3	1.3	3.3	11.8	58.8	0.1	0.3	3.3	13.7	1.3	1.5	4.5
71316	point/mineral in SI	s3	1.3	3.4	11.6	57.4		0.1	3.3	15.3	1.5	1.5	4.5
71316	point/mineral in SI	s7	1.2	2.1		63.6	0.2	0.3	3.1	14.0	0.8	1.5	3.4
71316	point/mineral in SI	s8	1.4	3.1	11.7	57.7			4.2	16.4	1.0	1.4	3.0
71316	point/mineral in SI	s11		0.1	0.6	93.4		0.4		0.3	1.4	0.7	3.0

Table G.1 (Continued)

71316	point/mineral in SI	s4	0.9	3.1	11.0	61.8		0.3	2.9	13.6	1.2	2.1	2.9
71316	point/mineral in SI	s8	1.3	3.1	11.6	57.3	0.2	0.2	4.3	16.5	1.2	1.5	2.9
71316	point/mineral in SI	s8	1.4	3.2	11.5	57.7		0.2	4.3	16.6	1.0	1.5	2.6
71320	point/mineral in SI	s4		0.1		0.2		0.1	0.1		0.1	0.4	98.6
71320	point/mineral in SI	s4		0.2	0.2	0.2	0.2	0.2	0.1			0.3	98.4
71320	point/mineral in SI	s4		0.3	0.4	1.2	0.3	0.2	0.2	0.2	0.3	0.7	96.1
71320	point/mineral in SI	s4		0.3	0.5	1.0	0.1	0.2	0.2	0.3	0.3	1.0	96.1
71320	point/mineral in SI	s7	0.4	0.5	0.5	0.9	0.6	0.2			0.1	0.9	95.9
71320	point/mineral in SI	s8			0.2	0.6	0.2	0.2			0.2	4.0	94.3
71320	point/mineral in SI	s8		0.1	0.2	0.6	0.1	0.2	0.2	0.2	0.3	3.8	94.3
71320	point/mineral in SI	s1	0.3	0.4	0.5	0.5					0.2	3.7	94.3
71320	point/mineral in SI	s4		0.4	0.8	2.7	0.3	0.2	0.2	0.3	0.3	0.9	94.1
71320	point/mineral in SI	s1	0.1	0.3	0.5	0.4	0.2	0.3	0.1	0.1	0.2	3.7	94.0
71320	point/mineral in SI	s7	0.5	0.7	0.6	2.0	0.7	0.5		0.1	0.2	1.0	93.7
71320	point/mineral in SI	s4	0.3	0.5	0.8	3.7	0.6	0.3	0.3	0.6	0.4	0.9	91.7
71320	point/mineral in SI	s2	0.4	0.7	0.5	3.4	0.5	0.4			0.3	2.6	91.0
71320	point/mineral in SI	s1	0.2	0.3	0.6	2.5	0.4	0.2	0.2	0.3	0.2	4.3	90.8
71320	point/mineral in SI	s1		0.3	0.7	3.1	0.3	0.2	0.2	0.3	0.2	4.4	90.3
71320	point/mineral in SI	s5	0.7	1.0	1.0	9.4	0.8	0.6		0.1	0.1	4.0	82.1
71320	point/mineral in SI	s2	0.1	0.2		19.8		0.2	0.2	0.2		1.9	77.2
71320	point/mineral in SI	s2	0.4	0.5	0.5	9.4	0.4	0.4		0.1	0.2	11.1	77.0
71320	point/mineral in SI	s2	0.1	0.2	0.2	23.5	0.1	0.1	0.1	0.1	0.2	2.0	73.4
71320	point/mineral in SI	s4	1.0	1.4	3.6	15.1	1.7	0.6	0.7	1.6	0.2	0.9	73.1
71320	point/mineral in SI	s1	0.2	0.5	1.7	14.0	1.8	0.3	0.5	1.8	0.2	7.2	72.0
71320	point/mineral in SI	s1	0.2	0.4	2.0	16.4	2.3	0.3	0.7	1.9	0.2	7.8	67.8
71320	point/mineral in SI	s3	0.1	0.8	3.8	20.8	1.5	0.5	1.5	3.5	0.4	1.5	65.6
71320	point/mineral in SI	s4	0.7	0.9	4.5	22.6	1.8	0.3	1.3	2.6	0.3	1.4	63.6
71320	point/mineral in SI	s3	0.5	1.1	4.6	22.8	1.4		1.3	2.8	0.3	1.5	63.5
71320	point/mineral in SI	s3	0.4	1.1	4.9	23.0	1.5		1.2	3.0	0.3	1.4	63.1

Table G.1 (Continued)

71320	point/mineral in SI	s8	0.2	0.2	0.5	18.1	5.2	1.6	0.4	0.9	0.4	11.0	61.7
71320	point/mineral in SI	s8			0.4	18.4	5.4	1.5	0.4	0.8	0.3	11.3	61.6
71320	point/mineral in SI	s4	0.5	0.6	4.5	24.0	2.0		1.7	3.6	0.3	1.7	61.2
71320	point/mineral in SI	s4	0.7	0.9	4.7	24.6	2.0	0.2	1.8	3.7	0.2	2.0	59.3
71320	point/mineral in SI	s3	0.6	1.0	4.9	25.5	1.9	0.4	2.0	4.5	0.5	1.8	56.9
71320	point/mineral in SI	s5		0.1		25.9	0.6	0.3			0.2	16.3	56.5
71320	point/mineral in SI	s2				14.9	0.3	0.4	0.1	0.6	0.5	27.5	55.6
71320	point/mineral in SI	s3	0.7	1.1	5.9	28.7	2.1	0.3	1.6	4.4	0.3	1.7	53.3
71320	point/mineral in SI	s2	0.1	0.2		15.5	0.2	0.4	0.2	0.8	0.4	29.1	53.0
71320	point/mineral in SI	s3	0.7	0.9	5.6	29.1	2.3	0.5	1.6	4.4	0.2	1.7	53.0
71320	point/mineral in SI	s1	0.5	0.6	3.3	26.0	3.5	1.2	0.9	3.4	0.2	8.5	51.7
71320	point/mineral in SI	s1	0.4	0.3	2.9	27.0	3.6	0.9	0.9	3.2	0.1	9.3	51.3
71320	point/mineral in SI	s1	0.5	0.5	3.4	28.5	3.8	0.8	1.2	3.2	0.3	9.0	48.8
71320	point/mineral in SI	s1	0.5	0.5	3.3	28.8	3.8	0.8	1.1	3.2	0.3	9.2	48.7
71320	point/mineral in SI	s2				50.4			0.1	0.1	0.1	1.7	47.3
71320	point/mineral in SI	s3	0.7	1.2	6.7	32.9	2.3	0.4	2.1	4.4	0.3	1.7	47.3
71320	point/mineral in SI	s3	0.8	1.2	6.8	32.8	2.4	0.5	2.3	4.5	0.4	1.7	46.6
71320	point/mineral in SI	s2	0.1	0.1	0.3			0.2	0.4	0.5	0.7	2.6	45.1
71320	point/mineral in SI	s6	0.1	0.2	1.1	20.7		1.6	0.2	2.0	0.7	29.9	43.5
71320	point/mineral in SI	s6			0.8	21.1		1.5	0.1	2.0	0.4	30.6	43.4
71320	point/mineral in SI	s9		0.5	0.4	28.4	2.6	1.0	0.5	5.6	0.3	26.7	34.0
71320	point/mineral in SI	s9	0.2	0.6	0.4	28.4	2.5	1.1	0.5	5.7	0.4	26.2	34.0
71320	point/mineral in SI	s6		0.1	0.7	86.4		0.2			0.1	1.1	11.1
71320	point/mineral in SI	s6		0.1	0.7	86.8		0.5	0.1	0.2	0.1	1.2	10.3
71320	point/mineral in SI	s7		0.1	1.2	35.6		3.2	0.3	3.3	0.6		5.6
71320	point/mineral in SI	s7			1.2	35.7		3.4	0.3	3.4	0.6	50.3	5.0
71321	point/mineral in SI	s2		0.2	0.3	0.4		0.2			0.2	0.3	98.3
71321	point/mineral in SI	s1		0.2	0.3	0.4	0.2	0.3	0.1			0.1	98.2
71321	point/mineral in SI	s1		0.1	0.3	0.5		0.1	0.1	0.2		0.4	98.1

Table G.1 (Continued)

71321	point/mineral in SI	s2			0.2	0.4		0.3	0.1	0.2	0.2	0.4	98.1
71321	point/mineral in SI	s1	0.1	0.1		0.3	0.2	0.2	0.1	0.2	0.3	0.4	97.9
71321	point/mineral in SI	s3		0.4	0.3	0.4		0.1		0.2	0.2	0.3	97.9
71321	point/mineral in SI	s4		0.3	0.6	0.4				0.2	0.3	0.3	97.9
71321	point/mineral in SI	s4		0.2	0.6	0.5		0.2		0.2	0.3	0.4	97.7
71321	point/mineral in SI	s2		0.2	0.4	0.4	0.3	0.2		0.2	0.3	0.2	97.7
71321	point/mineral in SI	s3	0.1	0.5	0.5	0.4		0.2		0.2	0.1	0.3	97.7
71321	point/mineral in SI	s4		0.2	0.5	0.4	0.1	0.3		0.1	0.2	0.5	97.6
71321	point/mineral in SI	s2			0.4	0.5	0.3	0.1	0.1	0.5	0.2	0.3	97.5
71321	point/mineral in SI	s3	0.1	0.4	0.5	0.5	0.1	0.3		0.1	0.2	0.2	97.5
71321	point/mineral in SI	s1		0.3	0.4	0.6		0.2	0.2		0.2	0.5	97.4
71321	point/mineral in SI	s3		0.3	0.5	0.6		0.2		0.2	0.4	0.3	97.4
71321	point/mineral in SI	s2		0.3	0.3	0.5	0.2	0.3	0.1	0.2	0.2	0.5	97.4
71321	point/mineral in SI	s2			0.4	0.6	0.4	0.2	0.2	0.4	0.2	0.4	97.3
71321	point/mineral in SI	s4		0.2	0.6	0.6	0.2	0.2			0.3	0.4	97.2
71321	point/mineral in SI	s4	0.3	0.6	0.8	0.7	0.4	0.2	0.1		0.2	0.4	96.1
71321	point/mineral in SI	s4	0.4	0.5	0.9	0.8	0.4	0.4		0.2	0.2	0.4	95.9
71321	point/mineral in SI	s1	0.1	0.2	0.4	0.7	0.8	0.7	0.4	1.2	0.3	0.7	94.5
71321	point/mineral in SI	s1		0.4	0.5	1.2	1.1	1.1	0.6	1.4	0.7	0.8	92.1
71321	point/mineral in SI	s5	0.2	0.4	0.5	0.6	11.0		0.2	12.4	0.2	0.3	74.2
71321	point/mineral in SI	s5		0.2	0.4	0.8	11.4	0.2	0.2	12.2	0.2	0.4	74.0
71321	point/mineral in SI	s4		0.5	2.8	7.9	11.4		0.4	4.5		0.6	71.8
71321	point/mineral in SI	s4	0.2	0.4	2.6	7.8	11.8		0.4	4.8	0.1	0.6	71.4
71321	point/mineral in SI	s3	0.2	0.5	2.8	19.5	1.5		1.5	3.4	0.2	0.4	7
71321	point/mineral in SI	s3		0.4	2.8	19.8	1.4		1.6	3.5	0.2	0.5	69.8
71321	point/mineral in SI	s3		0.4	2.7	20.2	1.6		1.8	3.1	0.1	0.3	69.7
71321	point/mineral in SI	s3	0.2	0.3	2.5	21.0	1.8	0.3	1.8	3.2	0.2	0.3	68.2
71321	point/mineral in SI	s2	0.2	0.4	3.7	26.2	0.3	0.2	0.2	2.1	0.2	0.4	66.0
71321	point/mineral in SI	s2	0.4	0.4	4.1	26.4	0.5	0.4	0.2	2.1	0.2	0.3	65.1

Table G.1 (Continued)

71321	point/mineral in SI	s2		0.4	3.6	24.2	1.5		1.4	6.2		0.2	62.4
71321	point/mineral in SI	s2	0.1	0.5	3.7	24.1	1.8		1.4	6.2	0.1	0.3	61.7
71321	point/mineral in SI	s3	0.2	0.4	3.2	22.3	4.5	0.3	1.5	5.7		0.2	61.6
71321	point/mineral in SI	s4	0.2	0.6	0.5	14.4	17.2	0.2	0.3	5.0	0.2	0.4	61.1
71321	point/mineral in SI	s4		0.6	0.7	14.5	17.1	0.1	0.3	5.1	0.2	0.4	61.0
71321	point/mineral in SI	s3	0.4	0.5	3.2	23.7	4.4		1.5	5.2	0.1	0.2	60.8
71321	point/mineral in SI	s3	0.3	0.5	3.8	24.7	3.7		1.4	4.9	0.1	0.4	
71321	point/mineral in SI	s3	0.3	0.5	3.7	25.2	3.9		1.5	5.1	0.1	0.2	59.4
71321	point/mineral in SI	s4	0.1	0.6	0.8	13.3	19.2		0.4	9.0	0.2	0.4	55.9
71321	point/mineral in SI	s4		0.5	0.9	13.1	19.4	0.1	0.4	9.4	0.3	0.5	55.3
71321	point/mineral in SI	s5	0.2	0.4	3.3	29.2	6.8		2.1	4.4		0.5	53.0
71321	point/mineral in SI	s2	0.2	0.2	0.7	4.7	17.3	0.1	0.5	22.8	0.3	0.4	52.9
71321	point/mineral in SI	s5	0.2	0.5	3.3	29.1	7.4	0.1	2.2	4.5	0.2	0.4	52.0
71321	point/mineral in SI	s2		0.2	0.7	5.1	17.8	0.2	0.5	23.5	0.2	0.2	51.7
71321	point/mineral in SI	s1	0.2	0.6	3.4	31.9	2.9		2.1	11.5		0.4	46.9
71321	point/mineral in SI	s1	0.2	0.3	3.3	32.3	3.0		2.1	11.5	0.1	0.3	46.7
71321	point/mineral in SI	s3	0.1	0.7	4.1	36.3	3.5		3.4	5.5	0.2	0.2	45.9
71321	point/mineral in SI	s3		0.8	4.7	36.5	3.6		3.2	5.5	0.4	0.3	45.1
71321	point/mineral in SI	s2	0.1	0.4	3.7	34.3	2.7		2.2	13.4	0.1	0.3	42.8
71321	point/mineral in SI	s2		0.4	4.0	34.3	2.7		2.2	13.4	0.2	0.4	42.5
71321	point/mineral in SI	s3	0.4	0.5	3.1	24.7	12.0	0.2	1.7	17.1		0.2	
71321	point/mineral in SI	s3	0.4	0.4	3.2	23.9	12.8	0.2	1.8	17.7	0.2	0.2	39.2
71321	point/mineral in SI	s3	0.3	0.6	0.6	3.3	28.5		1.7	32.4	0.3	0.4	31.8
71321	point/mineral in SI	s3	0.3	0.5	2.2	15.7	21.4	0.2	3.3	24.9	0.2	0.2	31.1
71321	point/mineral in SI	s3	0.3	0.5	2.3	15.6	21.9	0.1	3.3	25.4	0.2	0.2	30.2
71321	point/mineral in SI	s3	0.4	0.6	0.6	3.5	29.8		1.6	33.8	0.2	0.3	29.2
71321	point/mineral in SI	s1	0.2	0.5	2.5	10.6	23.0		1.6	33.2	0.2	0.3	27.9
71321	point/mineral in SI	s1	0.3	0.5	1.9	9.0	24.1		1.6	34.2	0.3	0.3	27.8
71321	point/mineral in SI	s3	0.5	0.5	1.1	8.2	26.4	0.3	2.4	36.1	0.2	0.2	24.2

Table G.1 (Continued)

71321	point/mineral in SI	s3	0.3	0.6	1.2	8.5	26.6	0.2	2.3	36.3	0.3	0.1	23.7
71321	point/mineral in SI	s5	0.2	0.7	0.6	5.1	33.5		0.9	37.0	0.1	0.2	21.7
71321	point/mineral in SI	s5	0.2	0.7	0.6	5.1	33.8		0.8	37.0		0.2	21.7
71321	point/mineral in SI	s3	0.3	0.4	0.5	3.8	32.6		2.2	40.9	0.2	0.2	18.8
71321	point/mineral in SI	s3	0.3	0.6	0.6	3.7	33.0		2.1	41.2	0.1	0.1	18.3
71321	point/mineral in SI	s5	0.2	0.5	0.3	2.7	37.3	0.3	0.5	44.2		0.2	13.8
71321	point/mineral in SI	s5	0.1	0.8	0.2	2.7	37.5		0.5	44.2	0.1	0.3	13.4
71321	point/mineral in SI	s3	0.2	0.4	0.7	5.4	33.2		1.1	45.4	0.2	0.3	13.1
71321	point/mineral in SI	s3	0.2	0.4	0.8	5.7	33.5		1.1	44.9		0.2	13.0
71321	point/mineral in SI	s3	0.3	0.6	0.6	4.4	35.6		1.5	45.1	0.2	0.3	11.4
71321	point/mineral in SI	s3	0.3	0.5	0.4	4.3	35.8	0.2	1.5	45.6		0.2	11.3

Appendix H- Indentification Results of Samples from Cemeteries

Table H.1 Identification results of sample from the Taicheng cemetery

		Materials			Shaping and fabrication				Surface treatment			
	Types	Decarburize steel	refined pig iron	Malleable cast iron	Casting	Welding	Wrap-welding	Forging	Cold forging	Quenching	Annealing	Carbonization
71303	Cha-spade			√	√							
71306	Spade	√	√			√					√	
71102	Ring-pommel knife	√						√	√			√
71104	Ring-pommel knife	√			√						√	
71105	Ring-pommel knife	√			√					√	√	
71301	Ring-pommel knife	√			?							
71304	Ring-pommel knife		√			√					?	
71305	Ring-pommel knife	√			√							√
71311	Ring-pommel knife	√			√					√		√
71315	Ring-pommel knife	√			√							
71313	Ring-pommel knife	√			√					√		√
71320	Ji halberd		√				√					√
71321	Sword		√					√				√
71300	Sword?	√										
71309	Ring-pommel knife?	√	√			√						√
71314	Knife?	√										
71312	Knife?		√									
71316	Knife	√						√	√			√

Table H.2 Identification results of sample from the Zhibai cemetery

		Materials				Shaping and fabrication				Surface treatment			
	Types	Decarburize steel	refined pig iron	Malleable cast iron	Wrought iron	Casting	Welding	Wrap-welding	Forging	Cold forging	Quenching	Annealing	Carbonization
71351	Fork		√				√		√				
71352	Ring-pommel knife		√?										
71353	Ring-head object	√											
71354	knife				√								
73155	Ring-pommel knife	√							√				
73156	Spoon-shaped tool												
73157	Dagger												
71358	Sword				√								
73159	Ring-pommel knife		√				√			√			

Table H.3 Identification results of sample from the Wanli cemetery

		Materials				Shaping and fabrication				Surface treatment			
	Types	Decarburize steel	refined pig iron	Malleable cast iron	Wrought iron	Casting	Welding	Wrap-welding	Forging	Cold forging	Quenching	Annealing	Carbonization
71323	Iron knife				√?								
71326	Iron caldron					√							
71327	Ring-pommel knife		√										
71328	Cha spade					√							
71330	Iron lamp					√							
71332	Cha spade		√				√		√	√		√	√
71333	Iron burner					√							
71336	Ring-pommel knife				√								
71340	Iron belt-hook					√							
71341	Ring-pommel knife		√				√?					√	